TABLE 14-19.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE D YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$251,627	$467,514	$1,367,389	$12,537,645
2014 O&M Cost	$217,989	$279,379	$672,379	$4,047,892
Total Annual Cost	**$469,615**	**$746,893**	**$2,039,768**	**$16,585,537**
Annual TP Load Reduction (lb/yr)	6,570	13,140	65,700	657,000
Estimated Cost for TP Reduction ($/lb TP removed)	$71.48	$56.84	$31.05	$25.24
Equation:[a]	$y = 489.23x^{-0.229}$			
R-Square Value:	0.9088			

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 14-20.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE D YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$251,627	$467,514	$1,367,389	$12,537,645
2014 O&M Cost	$217,144	$278,985	$666,583	$4,106,982
Total Annual Cost	**$468,771**	**$746,499**	**$2,033,972**	**$16,644,627**
Annual TP Load Reduction (lb/yr)	6,570	13,140	65,700	657,000
Estimated Cost for TP Reduction ($/lb TP removed)	$71.35	$56.81	$30.96	$25.33
Equation:[a]	$y = 483.82x^{-0.228}$			
R-Square Value:	0.906			

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

14.2 SEASONAL NUTRIENT REMOVAL

14.2.1 Extended Aeration Plants

Table 14-21 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective D seasonally for an extended aeration plant using mechanical aeration. Figures 14-21 and 14-22 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 14-22 and Figures 14-23 and 14-24 summarize these costs for an extended aeration plant using diffuser aeration. Tables 14-23 and 14-24 present the annualized unit costs for reducing nutrient loads for mechanical aeration and diffuser aeration plants, respectively.

TABLE 14-21.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE D SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.80	$1.11	$0.81
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.18	$0.12	$0.10

TABLE 14-22.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE D SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$2.06	$1.38	$0.89
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.17	$0.11	$0.08

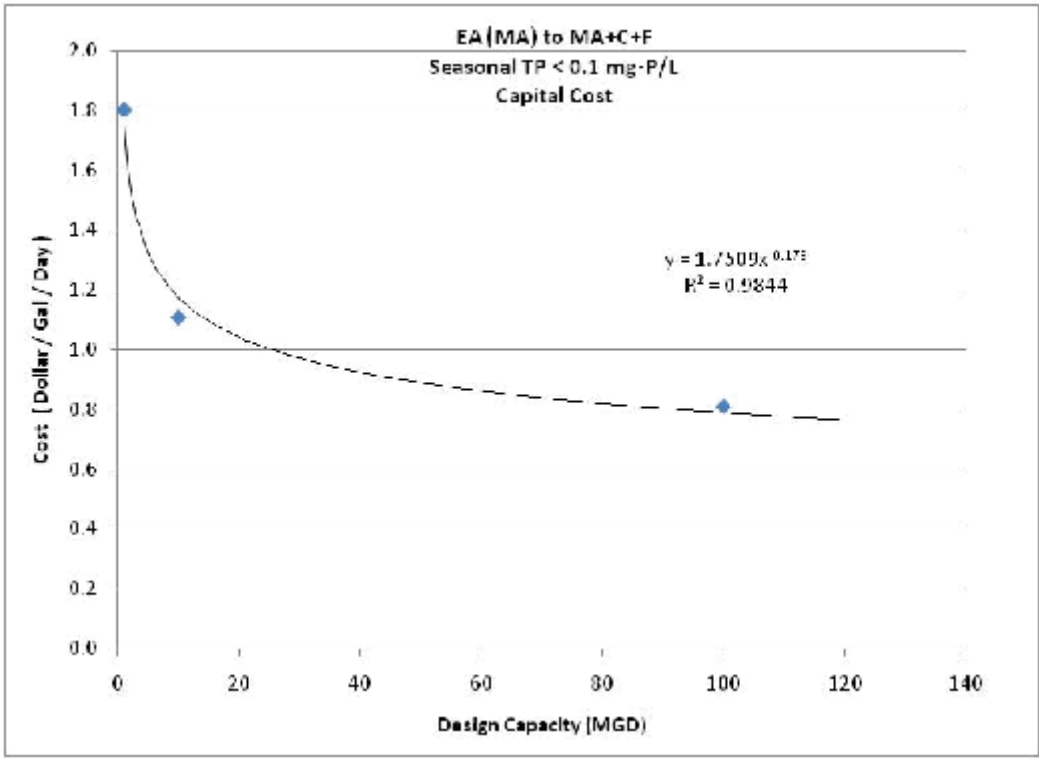


Figure 14-21. Capital Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective D Seasonally

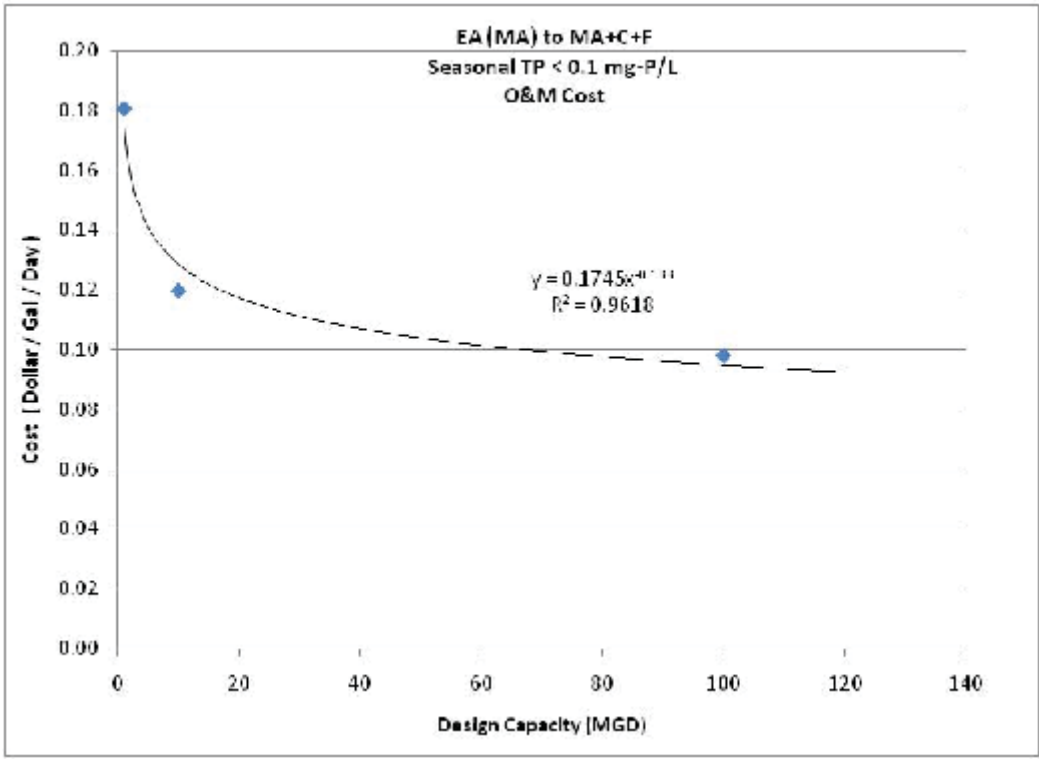


Figure 14-22. O&M Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective D Seasonal

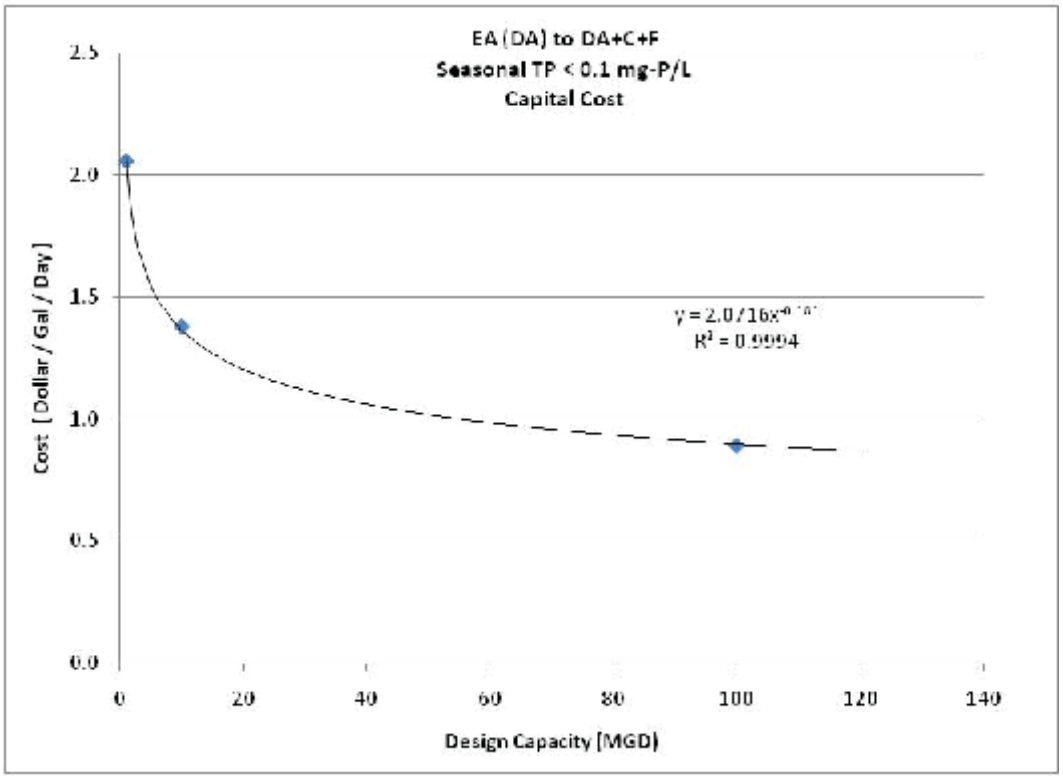


Figure 14-23. Capital Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective D Seasonally

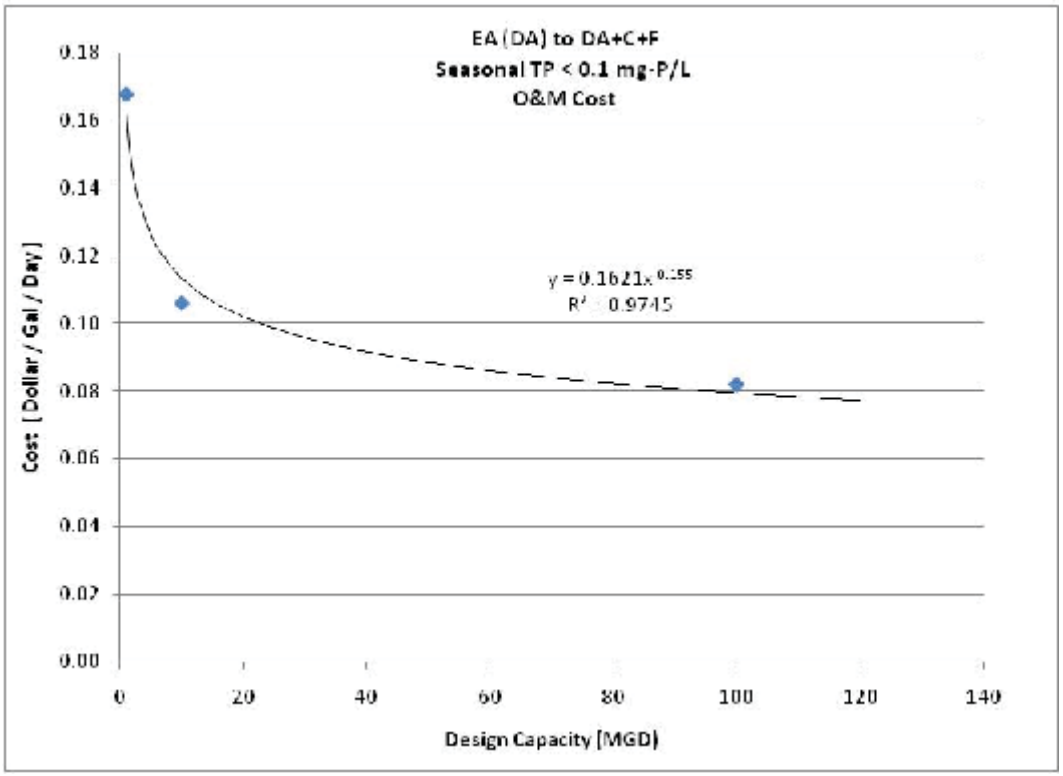


Figure 14-24. O&M Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective D Seasonal

TABLE 14-23.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EA (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE D SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$132,380	$814,509	$5,961,955
2014 O&M Cost	$203,379	$1,349,147	$11,047,094
Total Annual Cost	**$335,760**	**$2,163,657**	**$17,009,049**
Annual TP Load Reduction (lb/yr)	6,388	63,875	638,750
Estimated Cost for TP Reduction ($/lb TP removed)	$52.57	$33.87	$26.63
Equation:[a]			$y = 185.49x^{-0.148}$
R-Square Value:			0.9722

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 14-24.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EA ((DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE D SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$151,249	$1,013,995	$6,558,356
2014 O&M Cost	$188,692	$1,194,728	$9,241,215
Total Annual Cost	**$339,941**	**$2,208,723**	**$15,799,571**
Annual TP Load Reduction (lb/yr)	6,388	63,875	638,750
Estimated Cost for TP Reduction ($/lb TP removed)	$53.22	$34.58	$24.74
Equation:[a]			$y = 224.95x^{-0.166}$
R-Square Value:			0.9948

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

14.2.2 Conventional Activated Sludge Plants

Table 14-25 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective D seasonally for a conventional activated sludge plant. Figures 14-25 and 14-26 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 14-26 presents the annualized unit costs for reducing nutrient loads.

TABLE 14-25.
ESTIMATED COST PER CAPACITY FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE D SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$2.27	$1.15	$0.80
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.23	$0.13	$0.10

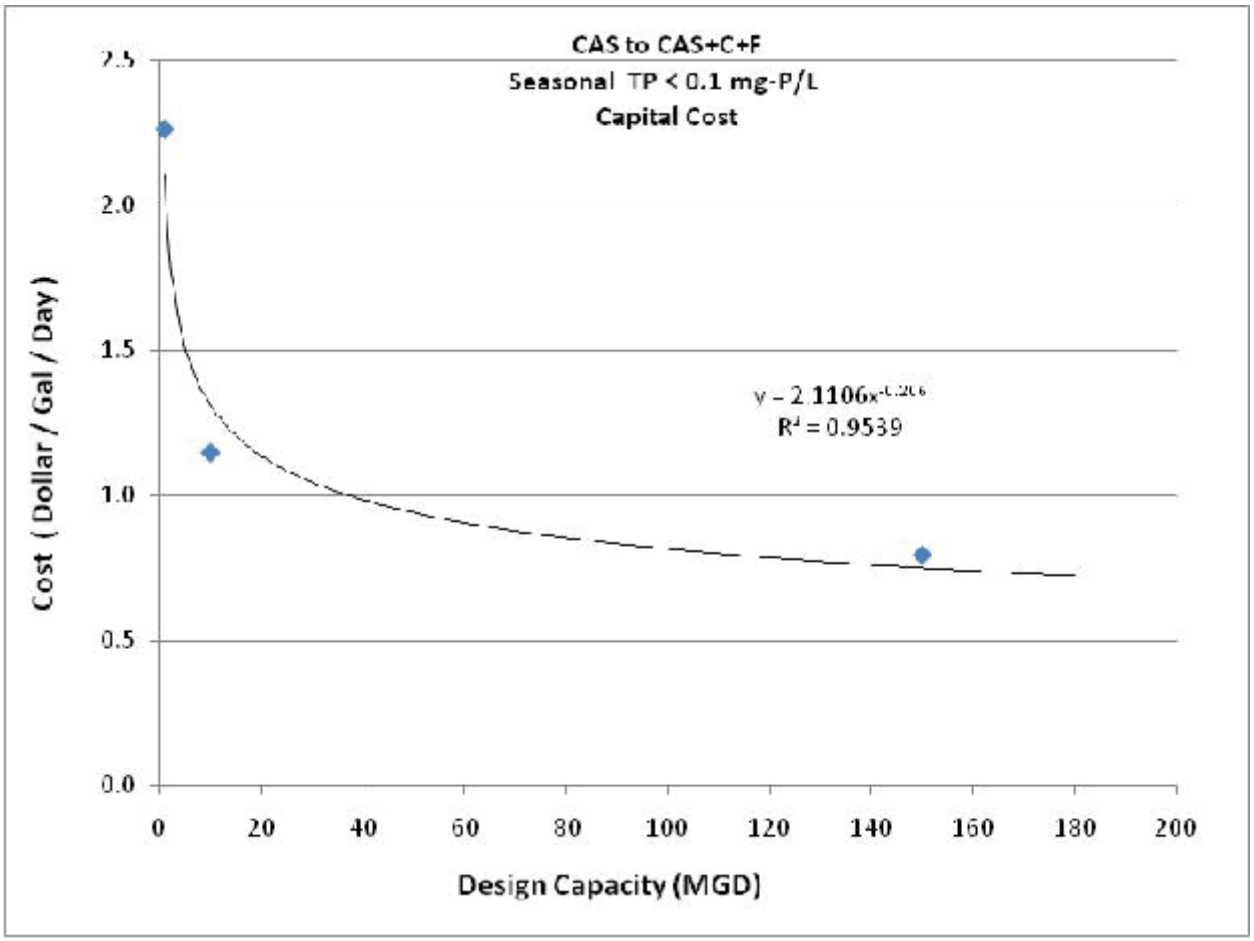


Figure 14-25. Capital Cost per Plant Capacity for CAS Plant Upgraded for Objective D Seasonally

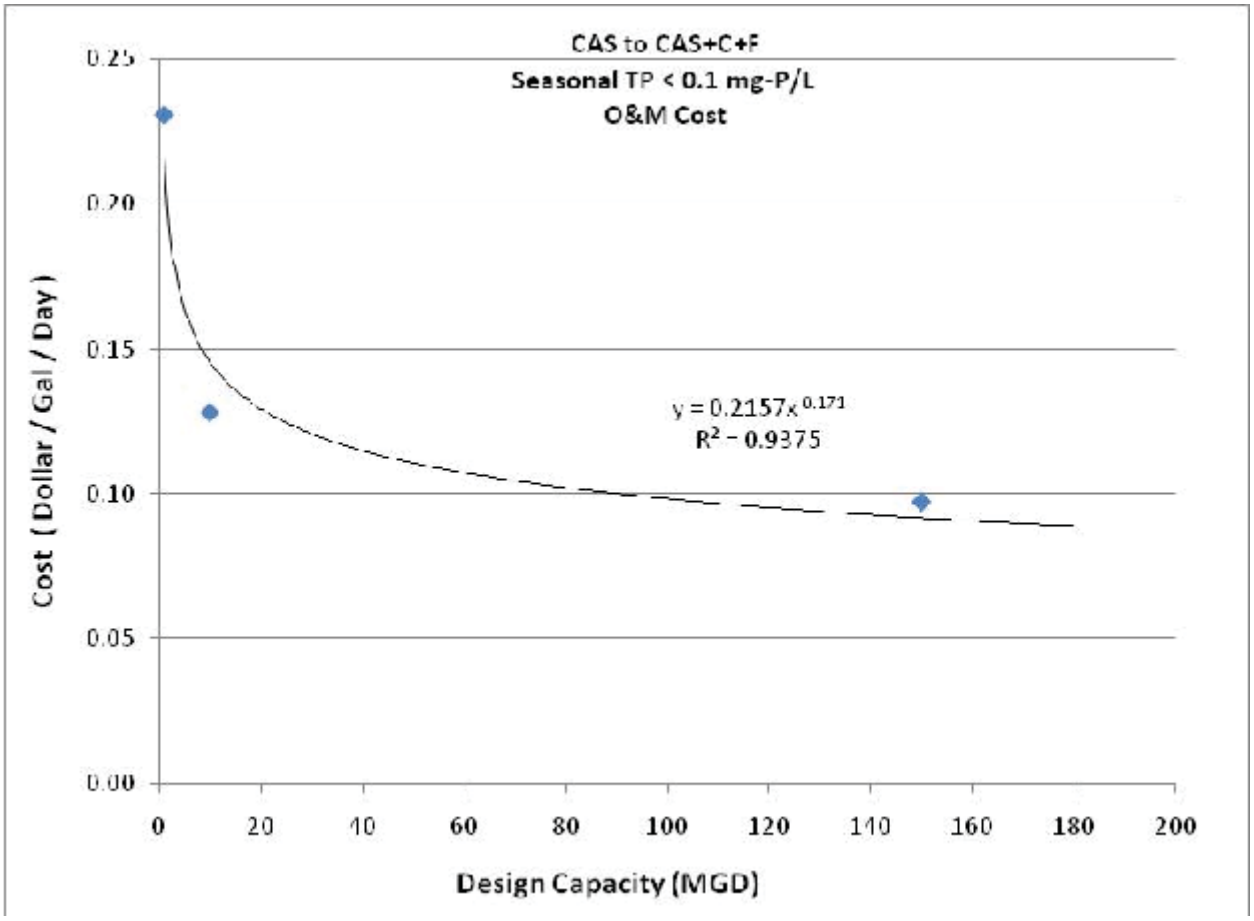


Figure 14-26. O&M Cost per Plant Capacity for CAS Plant Upgraded for Objective D Seasonal

TABLE 14-26.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE D SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$166,416	$845,327	$8,782,521
2014 O&M Cost	$260,128	$1,442,643	$16,418,247
Total Annual Cost	**$426,544**	**$2,287,970**	**$25,200,768**
Annual TP Load Reduction (lb/yr)	6,588	65,883	988,238
Estimated Cost for TP Reduction ($/lb TP removed)	$64.74	$34.73	$25.50
Equation:[a]			$y = 304x^{-0.184}$
R-Square Value:			0.9441

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

14.2.3 Sequencing Batch Reactor Plants

Table 14-27 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective D seasonally for an SBR plant. Figures 14-27 and 14-28 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 14-28 presents the annualized unit costs for reducing nutrient loads.

TABLE 14-27.
ESTIMATED COST PER CAPACITY FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE D SEASONALLY

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Capital Cost per gpd of Plant Capacity	$2.98	$1.81	$1.05
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.15	$0.07	$0.05

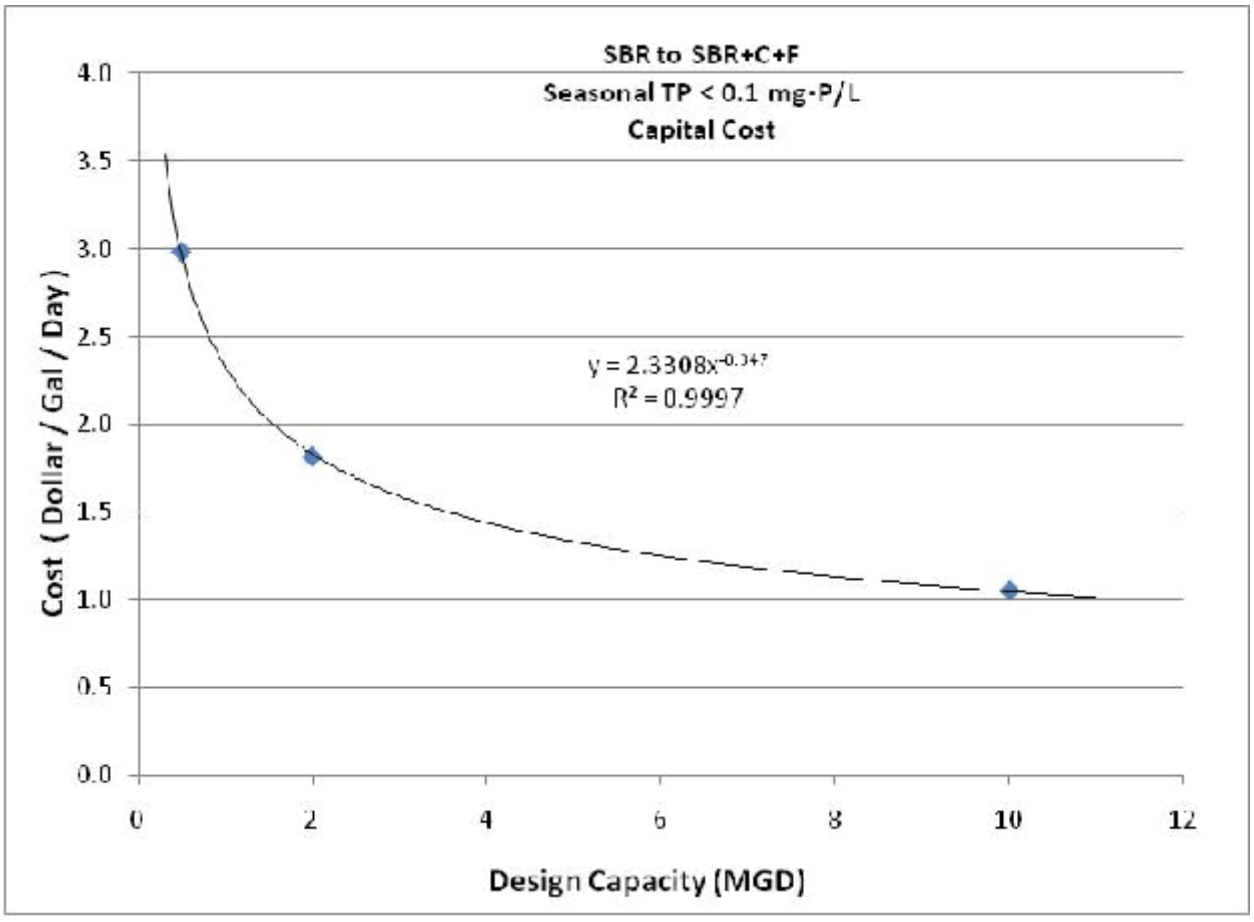


Figure 14-27. Capital Cost per Plant Capacity for SBR Plant Upgraded for Objective D Seasonally

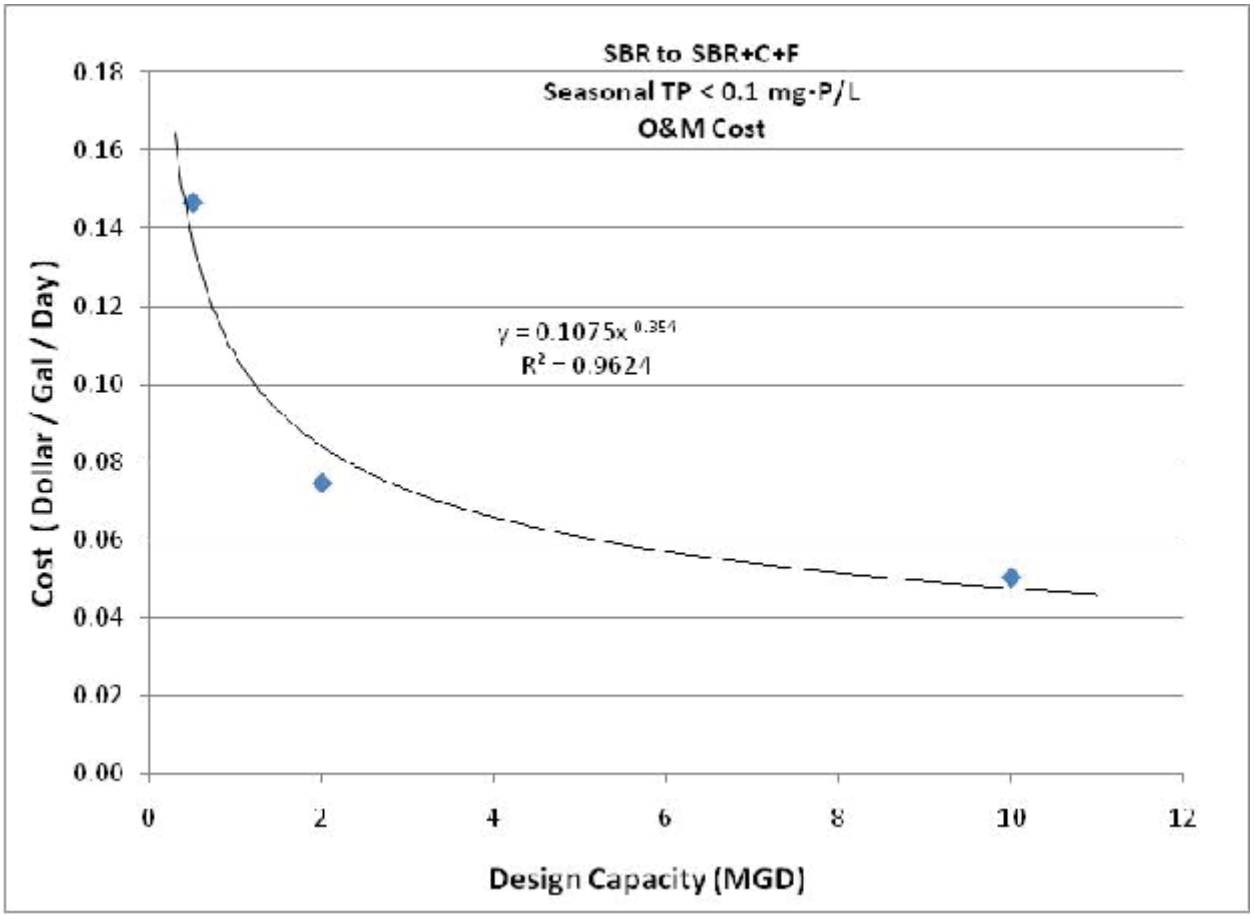


Figure 14-28. O&M Cost per Plant Capacity for SBR Plant Upgraded for Objective D Seasonal

TABLE 14-28.
UNIT NUTRIENT REMOVAL COSTS FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE D SEASONALLY

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Annualized Capital Cost	$109,450	$266,571	$773,265
2014 O&M Cost	$82,489	$167,701	$566,221
Total Annual Cost	**$191,938**	**$434,272**	**$1,339,486**
Annual TP Load Reduction (lb/yr)	1,487	5,950	29,748
Estimated Cost for TP Reduction ($/lb TP removed)	$129.05	$72.99	$45.03
Equation:[a]			$y = 1616x^{-0.35}$
R-Square Value:			0.9918

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

14.2.4 Trickling Filter, Trickling Filter/Solids Contact and Rotating Biological Contactor Plants

Table 14-29 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective D seasonally for a trickling filter plant. Figures 14-29 and 14-30 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 14-30 and Figures 14-31 and 14-32 summarize these costs for a trickling filter/solids contact plant. Table 14-31 and Figures 14-33 and 14-34 summarize these costs for an RBC plant. Tables 14-32, 14-33 and 14-34 present the annualized unit costs for reducing nutrient loads for TF, TF/SC and RBC plants, respectively.

TABLE 14-29.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER PLANT TO ACHIEVE OBJECTIVE D SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$2.27	$1.15	$0.80
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.22	$0.12	$0.09

TABLE 14-30.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER/SOLIDS CONTACT PLANT TO ACHIEVE OBJECTIVE D SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$2.27	$1.15	$0.80
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.22	$0.12	$0.09

TABLE 14-31.
ESTIMATED COST PER CAPACITY FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE D SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$2.27	$1.15	$0.80
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.22	$0.12	$0.09

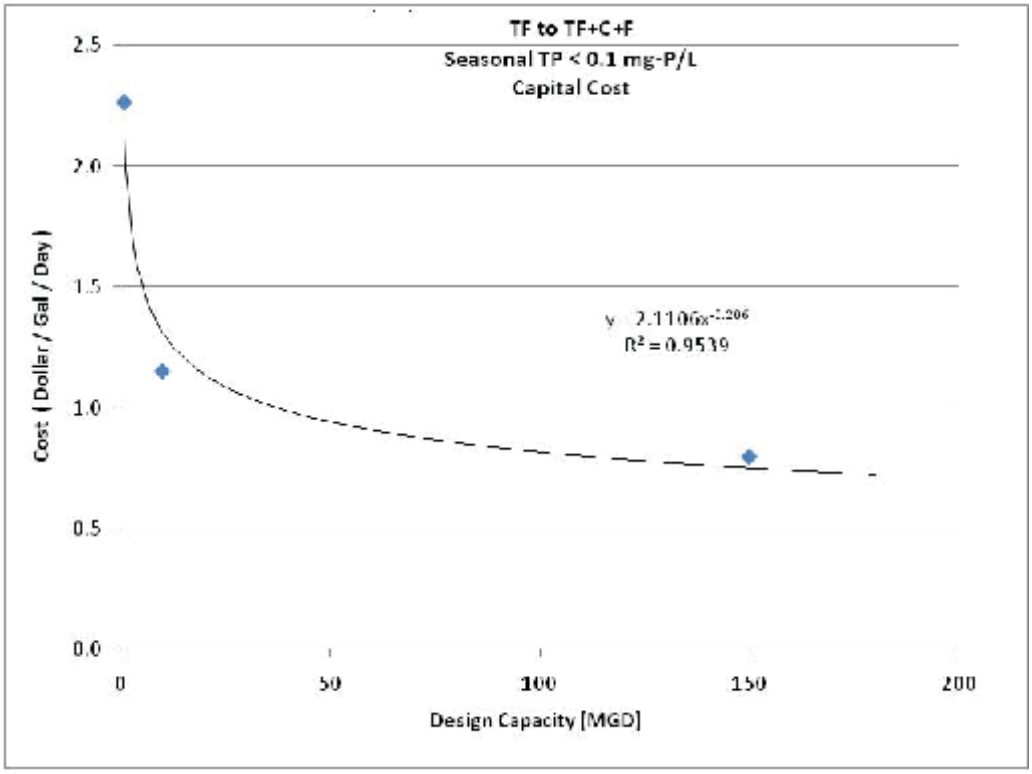


Figure 14-29. Capital Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective D Seasonally

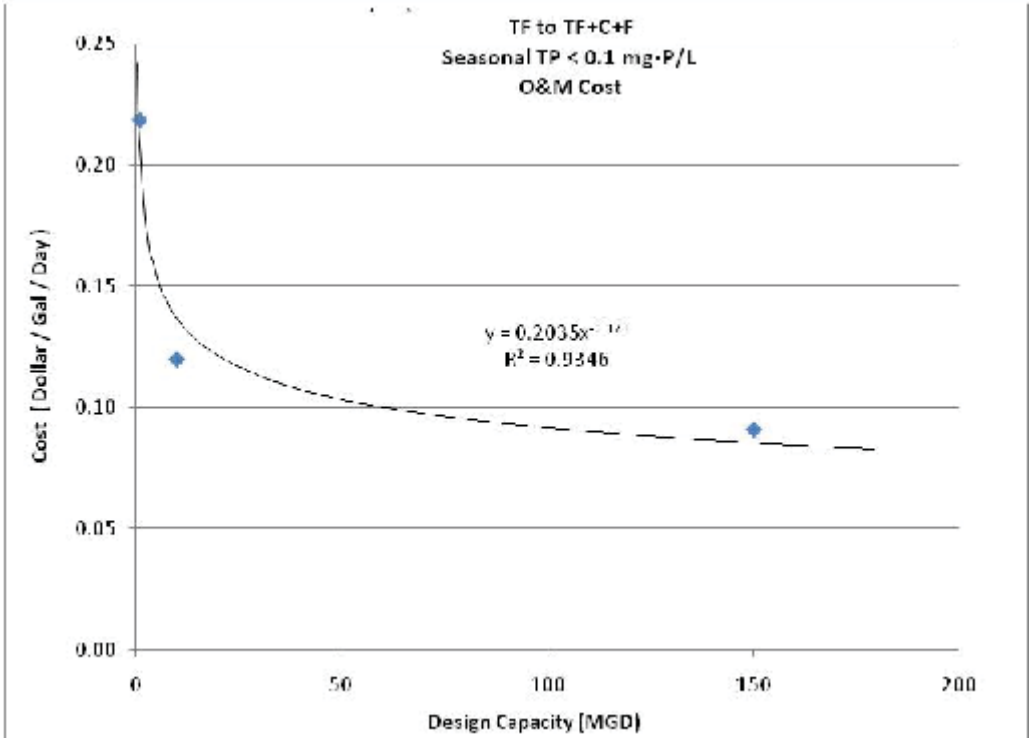


Figure 14-30. O&M Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective D Seasonal

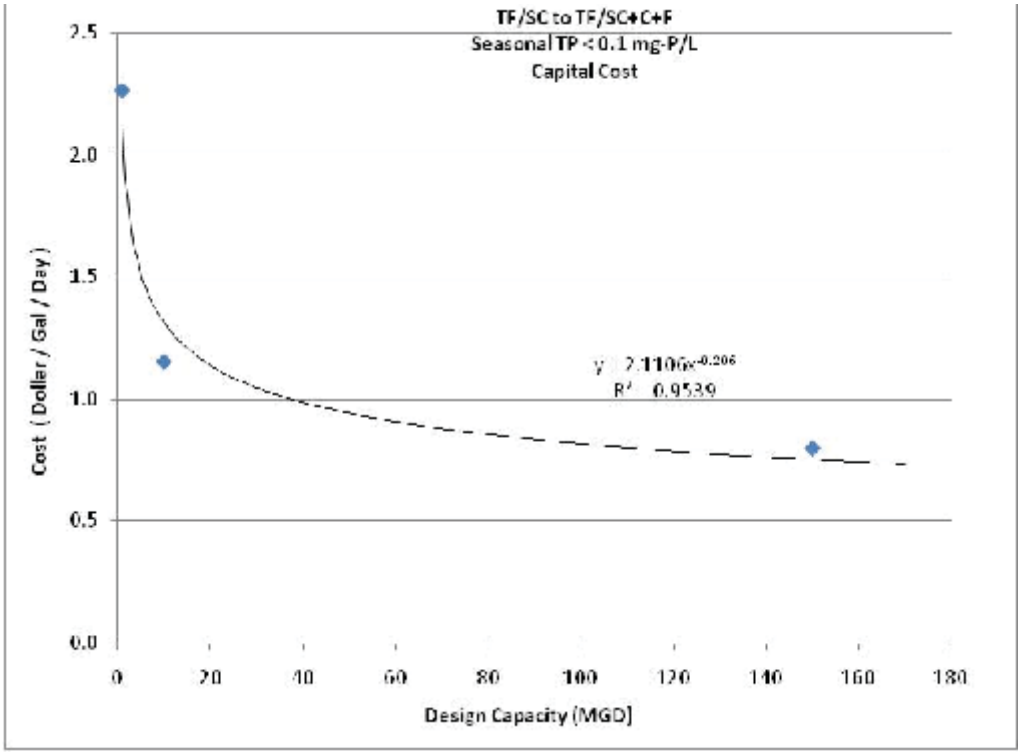


Figure 14-31. Capital Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective D Seasonally

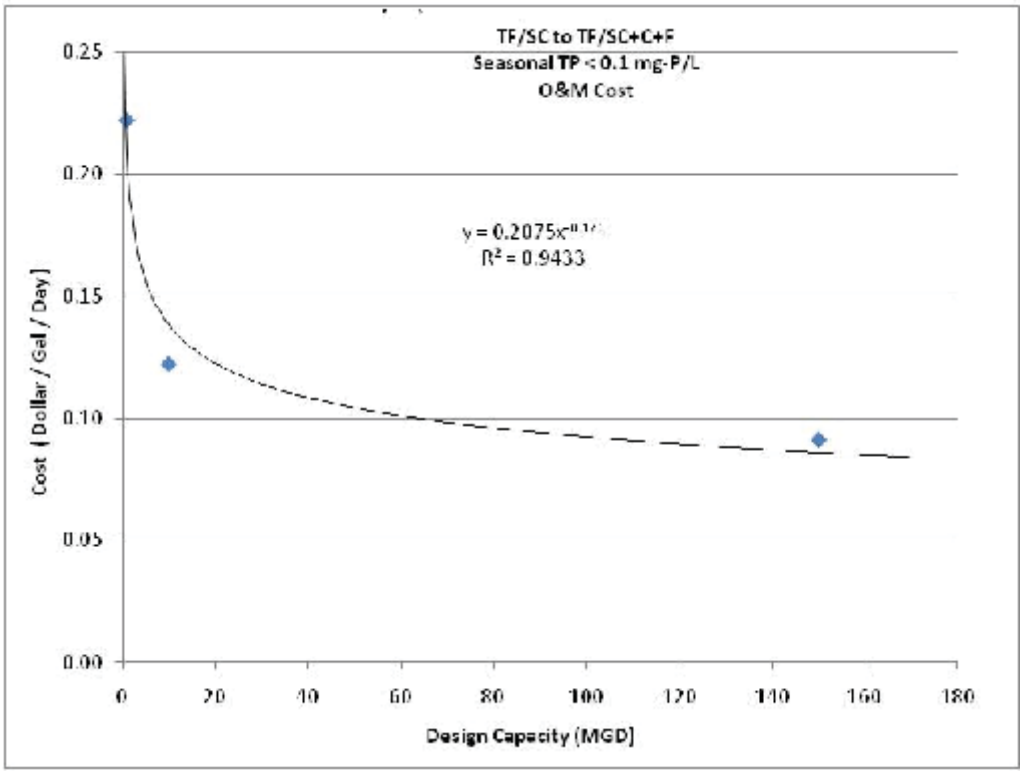


Figure 14-32. O&M Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective D Seasonal

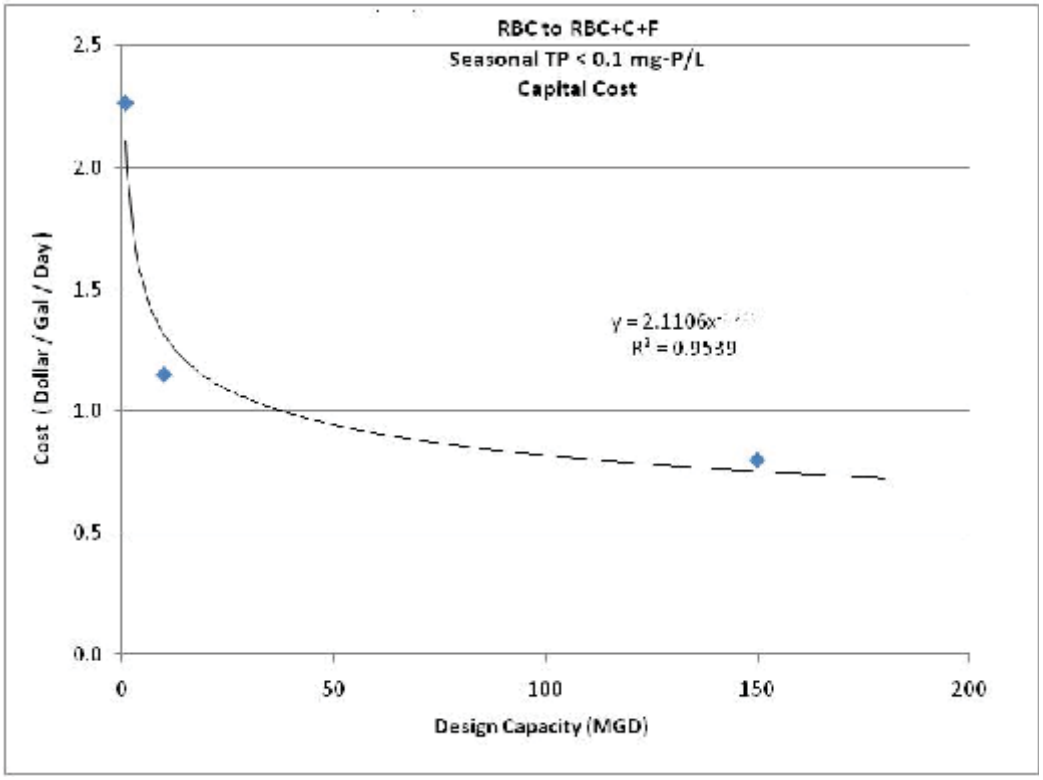


Figure 14-33. Capital Cost per Plant Capacity for RBC Plant Upgraded for Objective D Seasonally

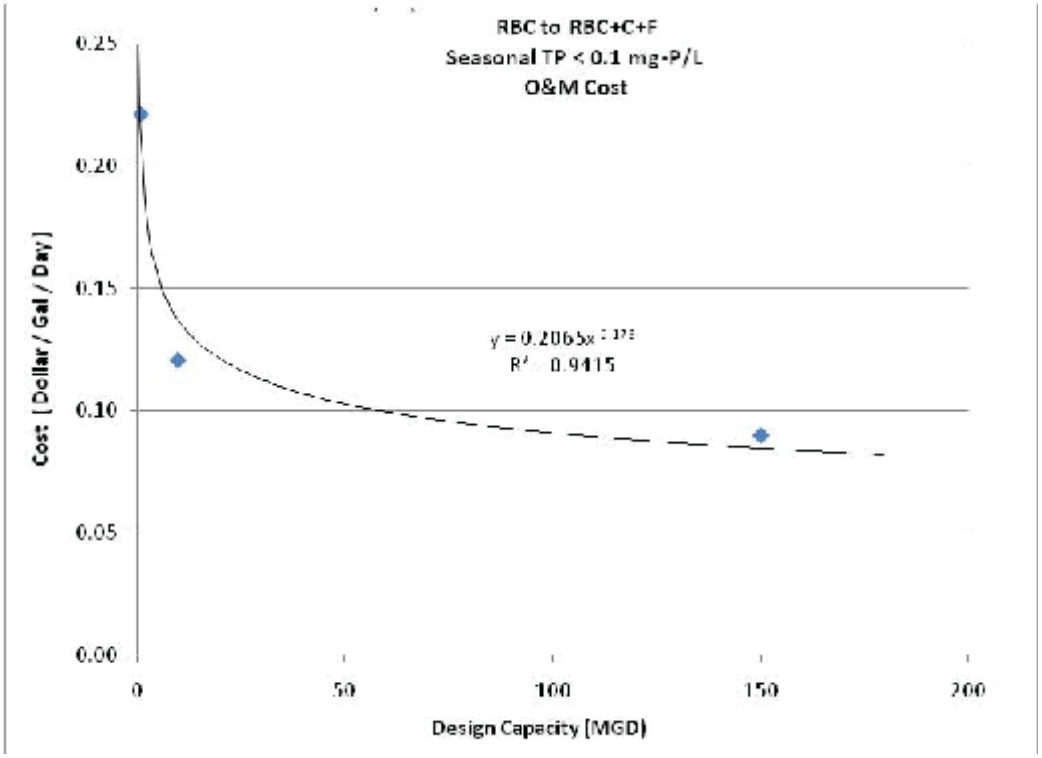


Figure 14-34. O&M Cost per Plant Capacity for RBC Plant Upgraded for Objective D Seasonal

TABLE 14-32.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TF PLANT TO ACHIEVE OBJECTIVE D SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$166,416	$845,327	$8,782,521
2014 O&M Cost	$246,014	$1,346,356	$15,331,006
Total Annual Cost	**$412,430**	**$2,191,683**	**$24,113,527**
Annual TP Load Reduction (lb/yr)	6,588	65,883	988,238
Estimated Cost for TP Reduction ($/lb TP removed)	$62.60	$33.27	$24.40
Equation:[a]			$y = 298.79x^{-0.186}$
R-Square Value:			0.9428

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 14-33.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TF/SC PLANT TO ACHIEVE OBJECTIVE D SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	166,416	845,327	8,782,521
2014 O&M Cost	$249,902	$1,374,438	$15,356,892
Total Annual Cost	**$416,319**	**$2,2197,64**	**$24,139,414**
Annual TP Load Reduction (lb/yr)	6,588	65,883	988,238
Estimated Cost for TP Reduction ($/lb TP removed)	$63.19	$33.69	$24.43
Equation:[a]			$y = 306.92x^{-0.188}$
R-Square Value:			0.9474

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 14-34.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE D SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$166,416	$845,327	$8,782,521
2014 O&M Cost	$249,188	$1,355,248	$15,128,977
Total Annual Cost	**$415,604**	**$2,200,574**	**$23,911,498**
Annual TP Load Reduction (lb/yr)	6,588	65,883	988,238
Estimated Cost for TP Reduction ($/lb TP removed)	$63.08	$33.40	$24.20
Equation:[a]			$y = 310.09x^{-0.189}$
R-Square Value:			0.9465

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

14.2.5 Membrane Biological Reactor Plants

Table 14-35 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective D seasonally for an MBR plant. Figures 14-35 and 14-36 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 14-36 presents the annualized unit costs for reducing nutrient loads.

TABLE 14-35.
ESTIMATED COST PER CAPACITY FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE D SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.19	$0.27	$0.03
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.15	$0.07	$0.05

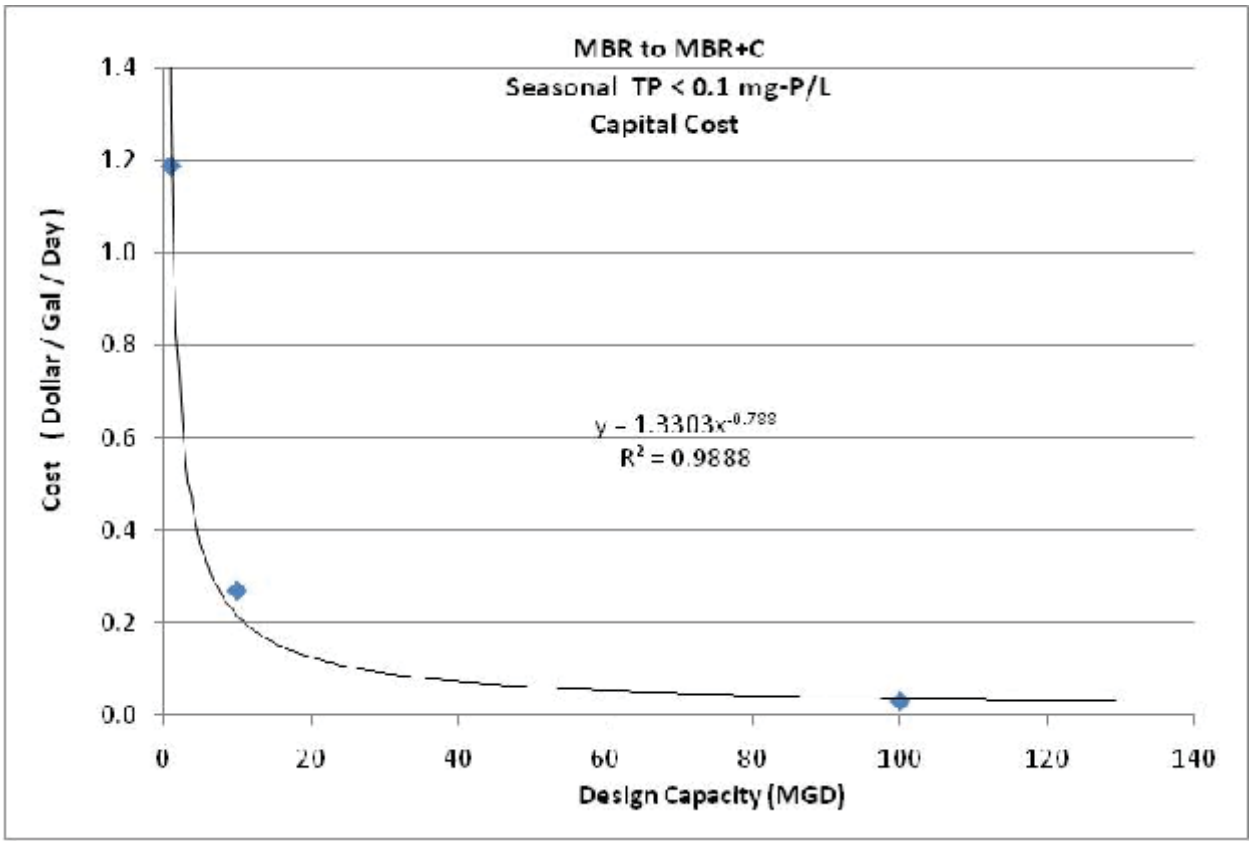


Figure 14-35. Capital Cost per Plant Capacity for MBR Plant Upgraded for Objective D Seasonally

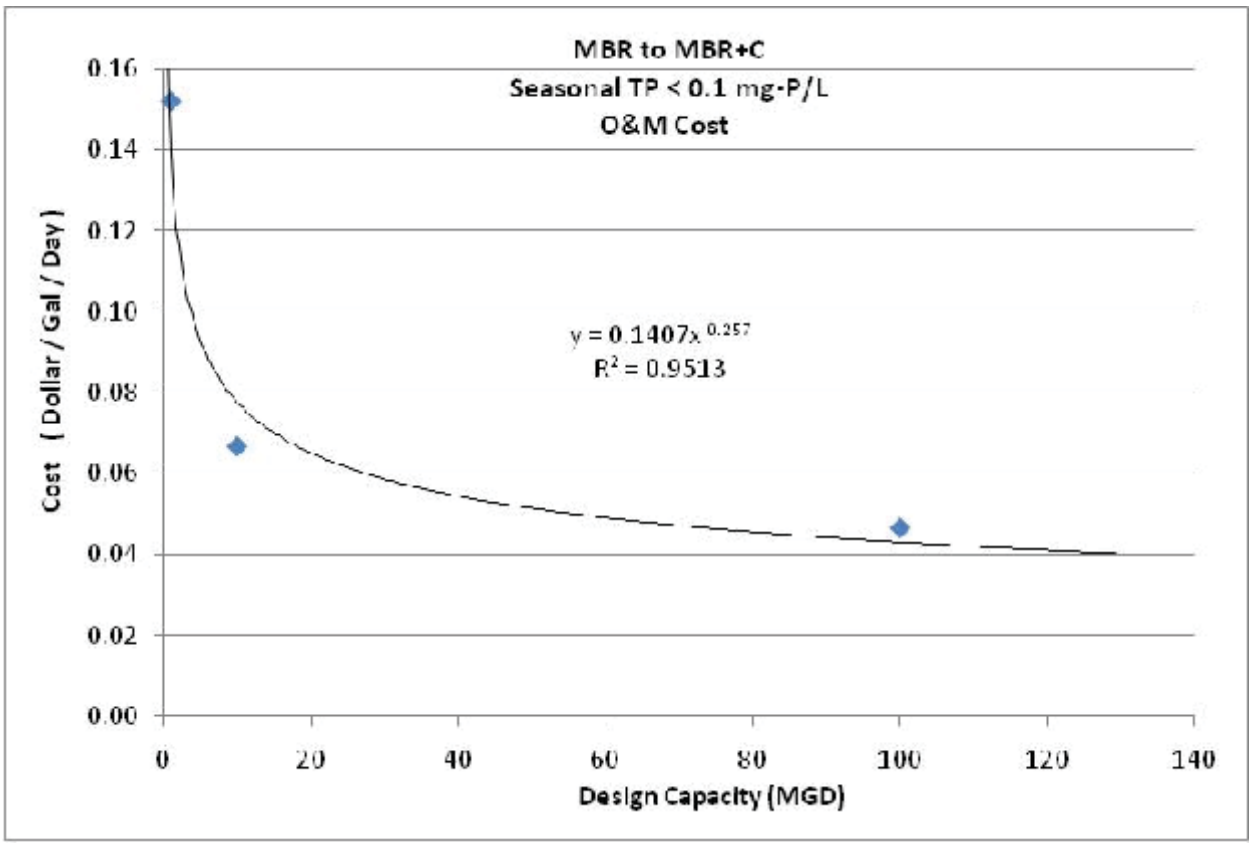


Figure 14-36. O&M Cost per Plant Capacity for MBR Plant Upgraded for Objective D Seasonal

TABLE 14-36.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE D SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$87,393	$198,859	$231,671
2014 O&M Cost	$171,139	$749,983	$5,229,902
Total Annual Cost	**$258,533**	**$948,841**	**$5,461,573**
Annual TP Load Reduction (lb/yr)	6,169	61,685	616,850
Estimated Cost for TP Reduction ($/lb TP removed)	$41.91	$15.38	$8.85
Equation:[a]			$y = 740.77x^{-0.338}$
R-Square Value:			0.9729

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

14.2.6 High-Purity Oxygen Activated Sludge Plants

High-purity oxygen activated sludge plants were not evaluated for any objectives that include phosphorus removal, so no costs associated with Objective D were developed for these plants.

14.2.7 Aerated or Facultative Lagoon Plants

Table 14-37 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective D seasonally for an aerated lagoon plan. Figures 14-37 and 14-38 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 14-38 and Figures 14-39 and 14-40 summarize these costs for a facultative lagoon plant. Tables 14-39 and 14-40 present the annualized unit costs for reducing nutrient loads for aerated lagoon and facultative lagoon plants, respectively.

TABLE 14-37.
ESTIMATED COST PER CAPACITY FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE D SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$6.40	$4.66	$3.01	$2.60
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.40	$0.25	$0.13	$0.06

TABLE 14-38.
ESTIMATED COST PER CAPACITY FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE D SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$6.40	$4.66	$3.01	$2.60
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.37	$0.23	$0.10	$0.05

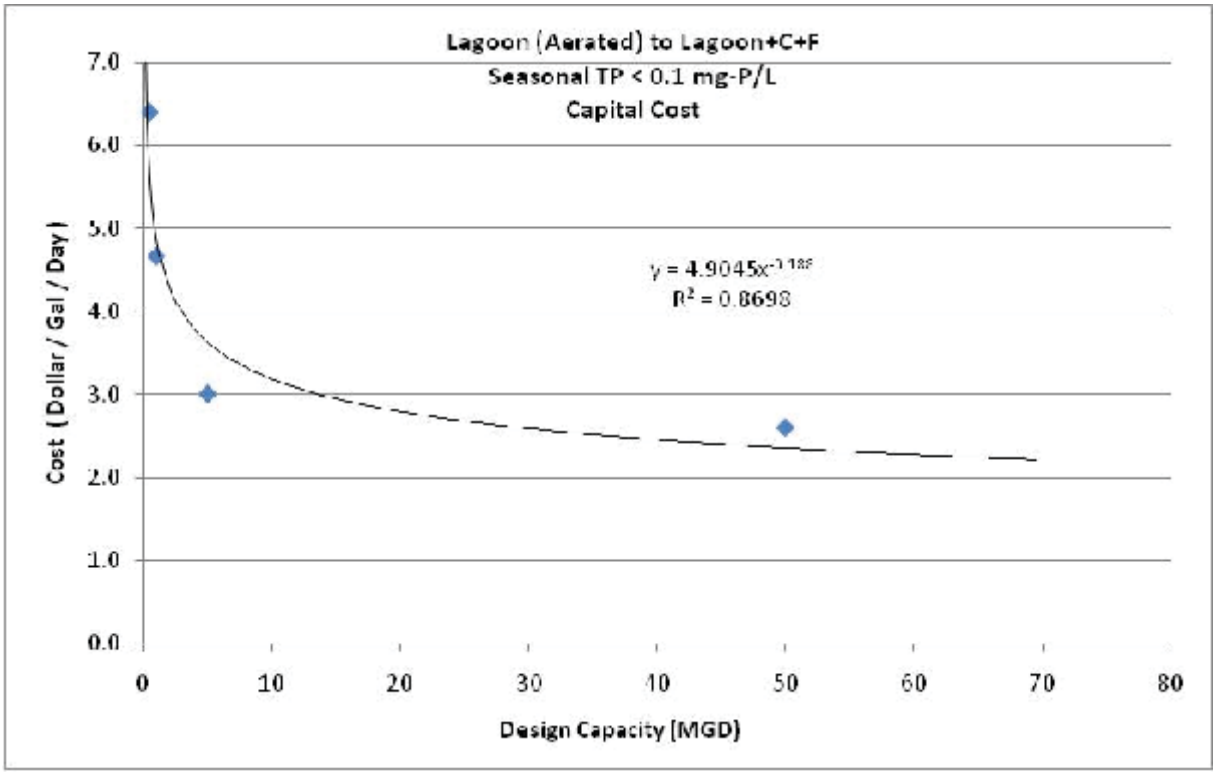


Figure 14-37. Capital Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective D Seasonally

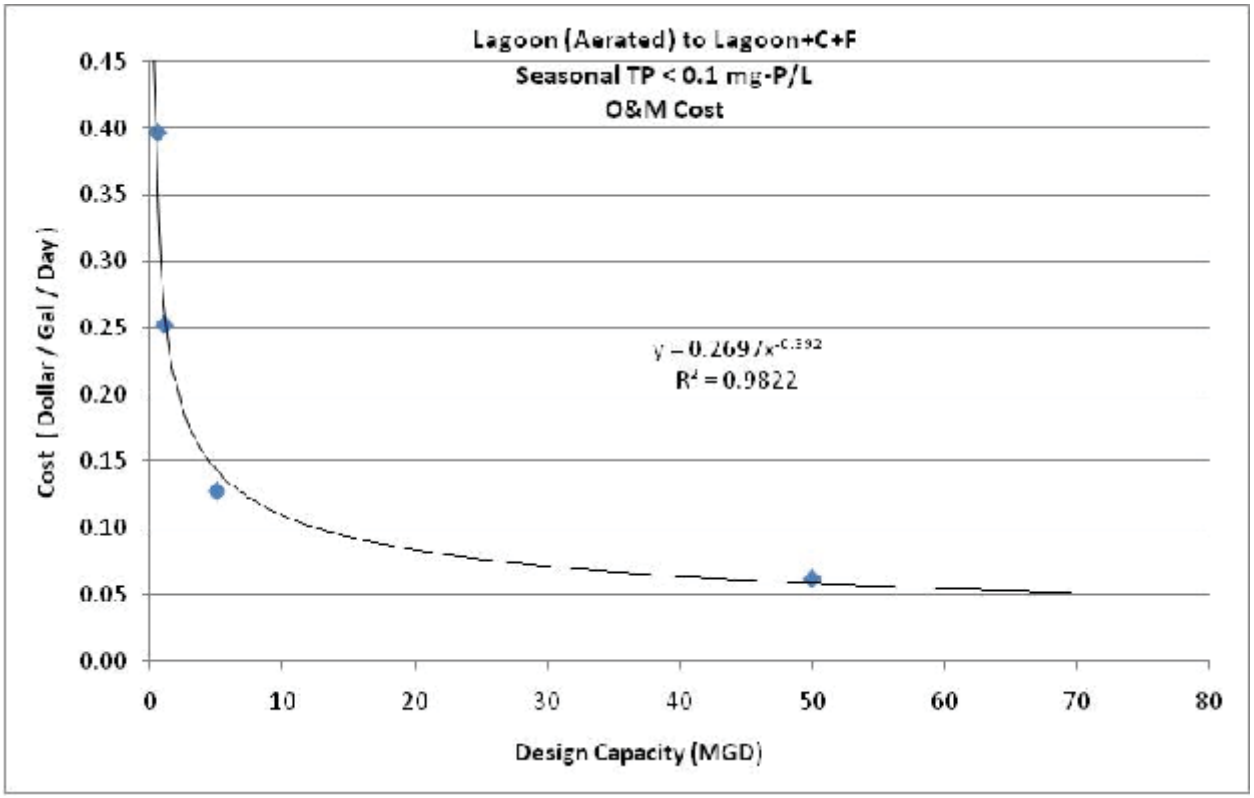


Figure 14-38. O&M Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective D Seasonal

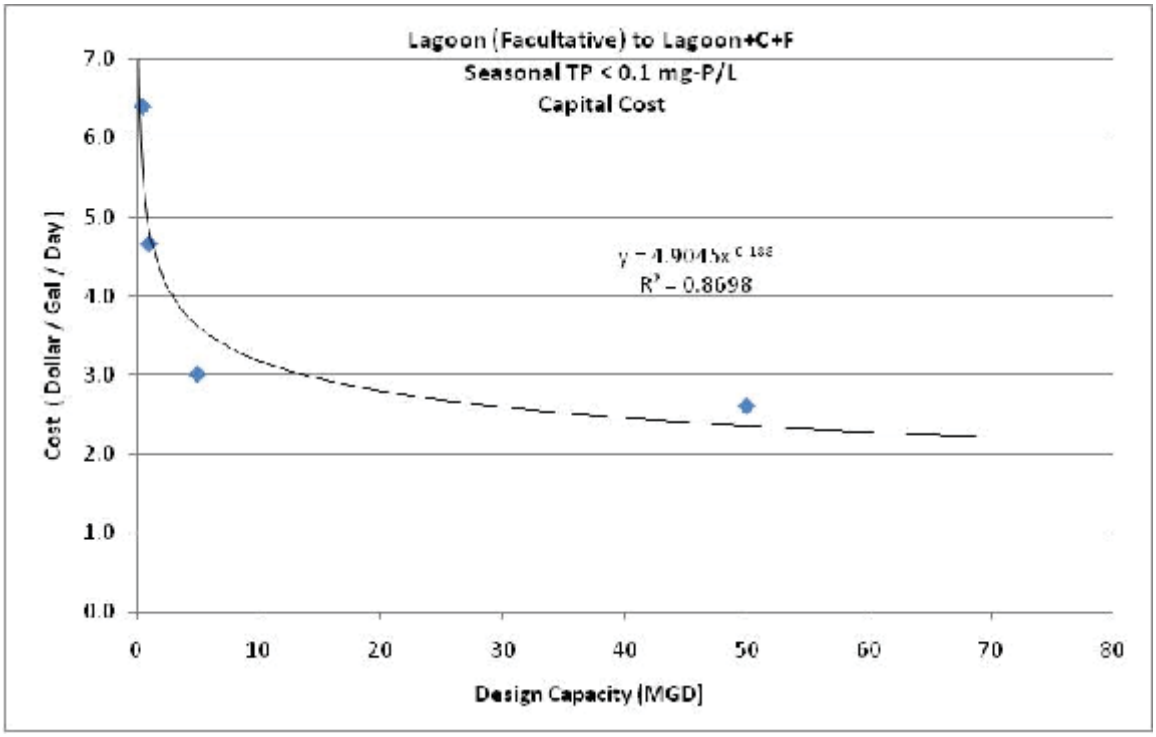


Figure 14-39. Capital Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective D Seasonally

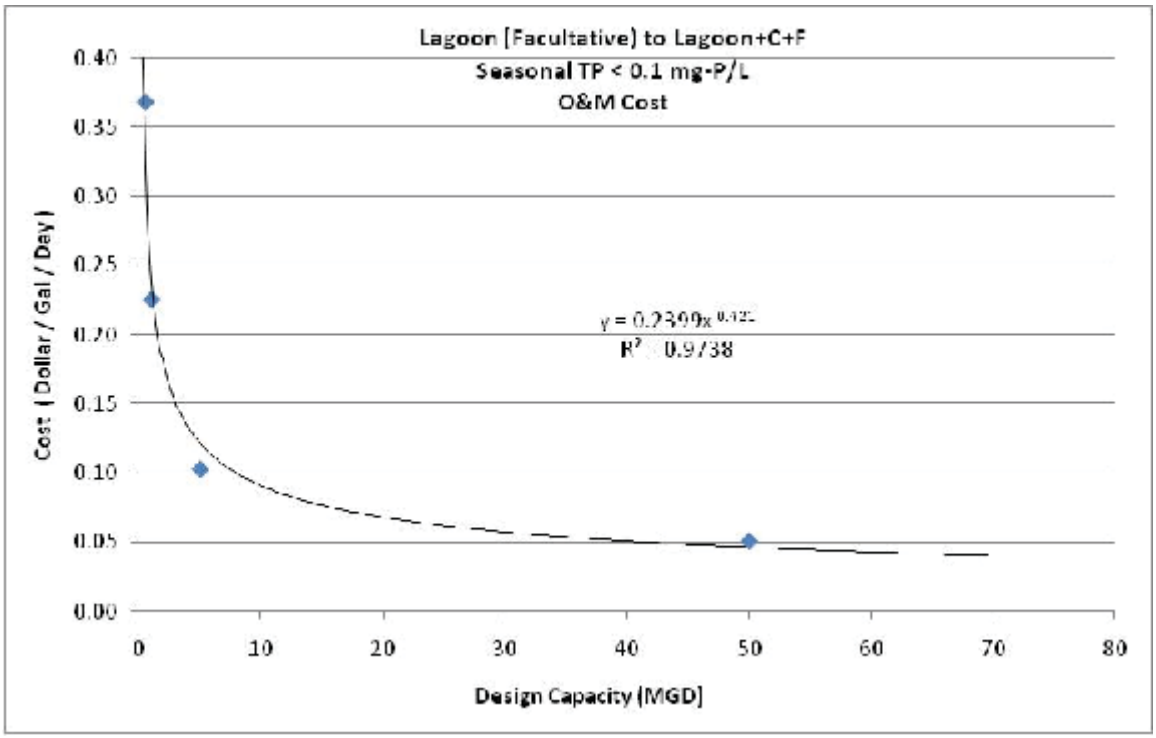


Figure 14-40. O&M Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective D Seasonal

TABLE 14-39.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE D SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$235,020	$342,527	$1,105,178	$9,565,922
2014 O&M Cost	$223,166	$284,253	$719,425	$3,500,332
Total Annual Cost	**$458,186**	**$626,780**	**$1,824,604**	**$13,066,254**
Annual TP Load Reduction (lb/yr)	3,294	6,588	32,941	329,413
Estimated Cost for TP Reduction ($/lb TP removed)	$139.09	$95.14	$55.39	$39.67
Equation:[a]	$y = 1023.5x^{-0.263}$			
R-Square Value:	0.9326			

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 14-40.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE D SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$235,020	$342,527	$1,105,178	$9,562,922
2014 O&M Cost	$207,268	$253,864	$578,568	$2,851,477
Total Annual Cost	**$442,288**	**$596,391**	**$1,683,746**	**$12,417,399**
Annual TP Load Reduction (lb/yr)	3,294	6,588	32,941	329,413
Estimated Cost for TP Reduction ($/lb TP removed)	$134.27	$90.52	$51.11	$37.70
Equation:[a]	$y = 1003.4x^{-0.267}$			
R-Square Value:	0.9193			

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

CHAPTER 15.
COST EVALUATION, OBJECTIVE E

15.1 YEAR-ROUND NUTRIENT REMOVAL

15.1.1 Extended Aeration Plants

Table 15-1 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective E year-round for an extended aeration plant using mechanical aeration. Figures 15-1 and 15-2 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 15-2 and Figures 15-3 and 15-4 summarize these costs for an extended aeration plant using diffuser aeration. Tables 15-3 and 15-4 present the annualized unit costs for reducing nutrient loads for mechanical aeration and diffuser aeration plants, respectively.

TABLE 15-1.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE E YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$5.28	$2.34	$2.33
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.39	$0.14	$0.09

TABLE 15-2.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE E YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.56	$0.84	$0.44
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.20	$0.08	$0.05

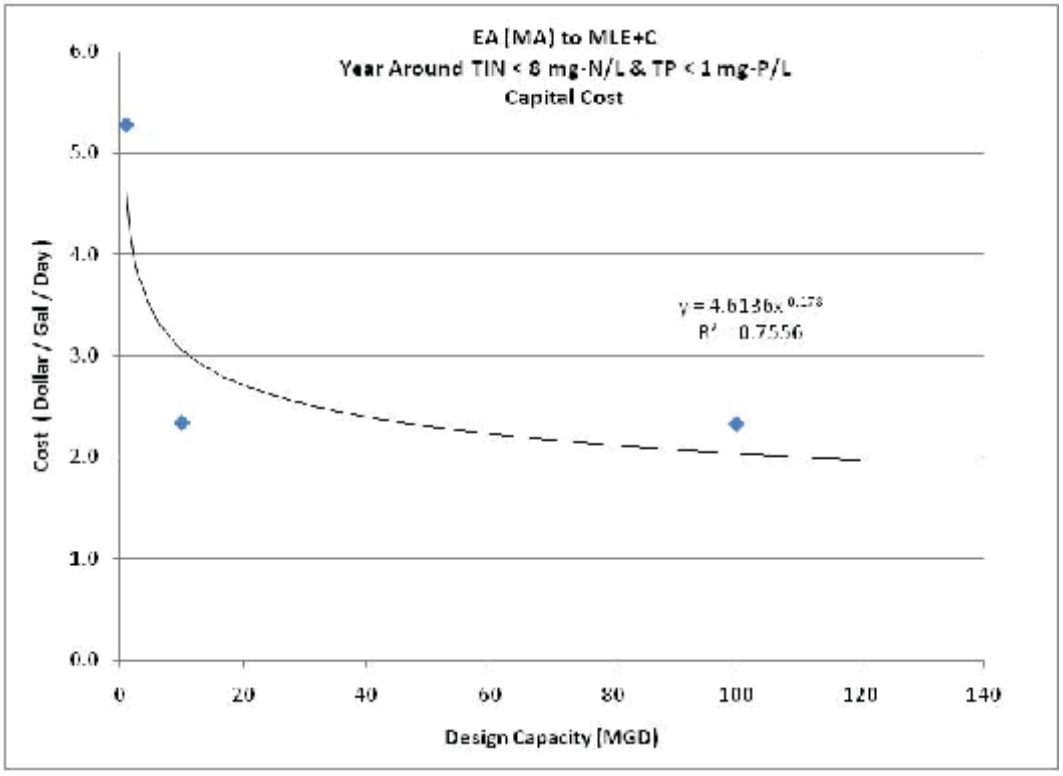


Figure 15-1. Capital Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective E Year-Round

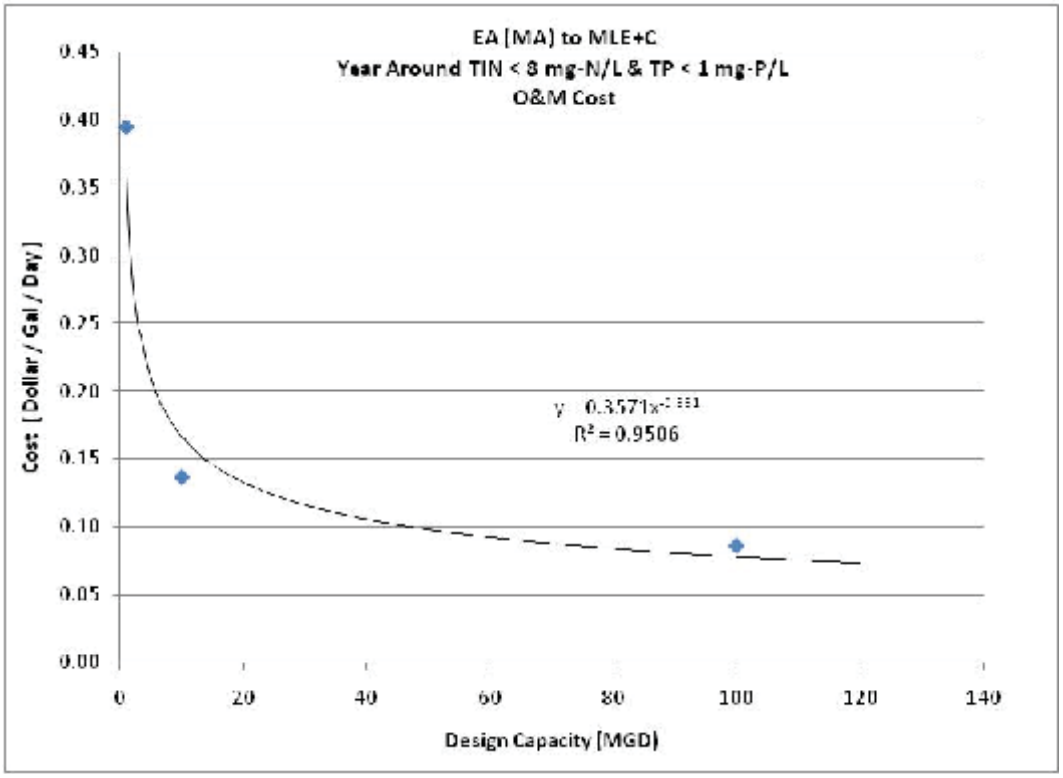


Figure 15-2. O&M Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective E Year-Round

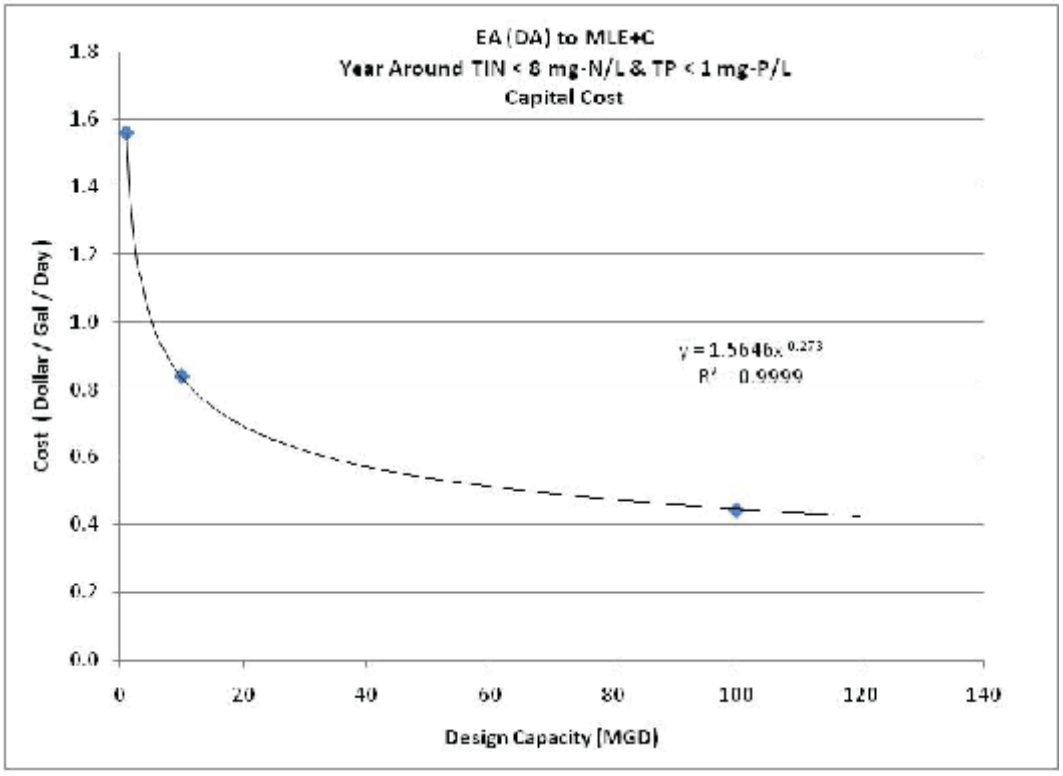


Figure 15-3. Capital Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective E Year-Round

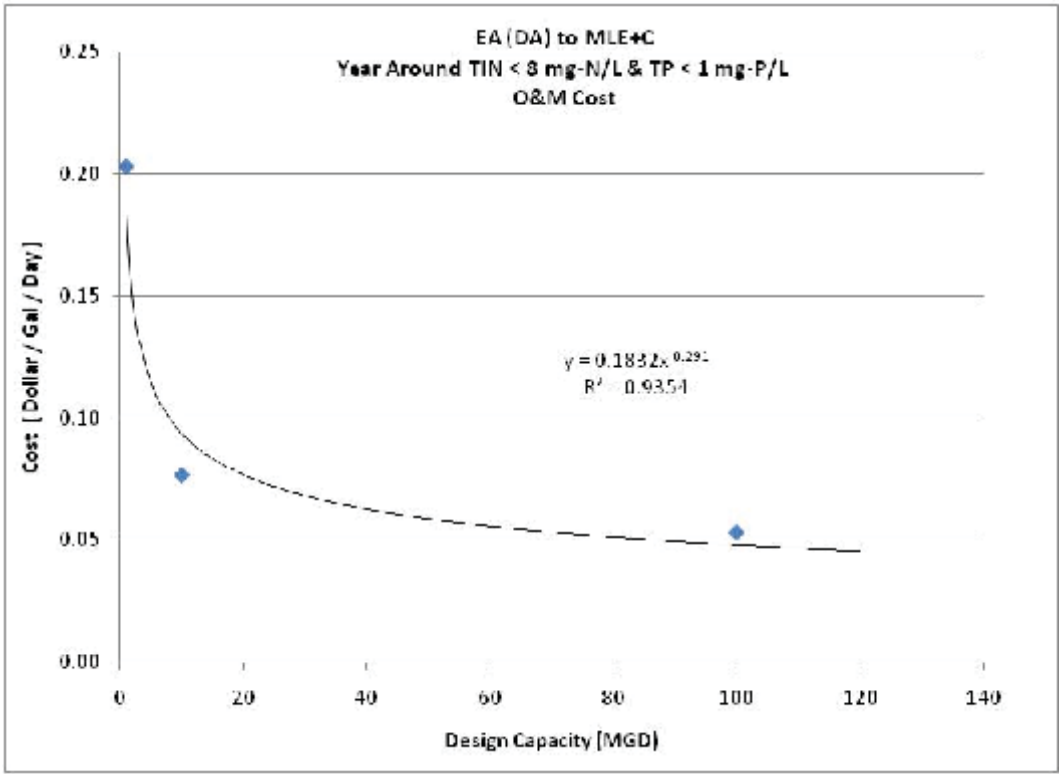


Figure 15-4. O&M Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective E Year-Round

TABLE 15-3.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EXTENDED AERATION (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE E YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$387,599	$1,720,185	$17,097,022
2014 Incremental O&M Cost	$444,351	$1,534,699	$9,678,363
Total Annual Cost	**$831,950**	**$3,254,884**	**$26,775,385**
Annual TIN Load Reduction (lb/yr)	35,442	35,4415	3,544,150
Annual TP Load Reduction (lb/yr)	11,060	110,595	1,105,950
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$15.87	$4.21	$3.06
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$24.38	$15.93	$14.41
TIN Cost Equation:[a]			$y = 567.22x^{-0.357}$
TIN Cost R-Square Value:			0.8889
TP Cost Equation:[b]			$y = 66.869x^{-0.114}$
TP Cost R-Square Value:			0.8869

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 15-4.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EXTENDED AERATION (DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE E YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$114,488	$617,872	$3,260,515
2014 Incremental O&M Cost	$228,309	$861,307	$5,979,378
Total Annual Cost	**$342,798**	**$1,479,178**	**$9,239,893**
Annual TIN Load Reduction (lb/yr)	35,442	354,415	3,544,150
Annual TP Load Reduction (lb/yr)	11,023	110,230	1,102,300
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$3.03	-$0.05	-$0.77
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$21.35	$13.58	$10.85
TIN Cost Equation and R-Square Value[a]			
TP Cost Equation:[b]			$y = 80.732x^{-0.147}$
TP Cost R-Square Value:			0.9636

a. Equation and R-square value for TIN not determined because annual cost estimates are below the level of precision that can be achieved using the CapdetWorks cost model.
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

15.1.2 Conventional Activated Sludge Plants

Table 15-5 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective E year-round for a conventional activated sludge plant. Figures 15-5 and 15-6 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 15-6 presents the annualized unit costs for reducing nutrient loads.

TABLE 15-5.
ESTIMATED COST PER CAPACITY FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE E YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$7.69	$4.73	$3.45
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.44	$0.25	$0.17

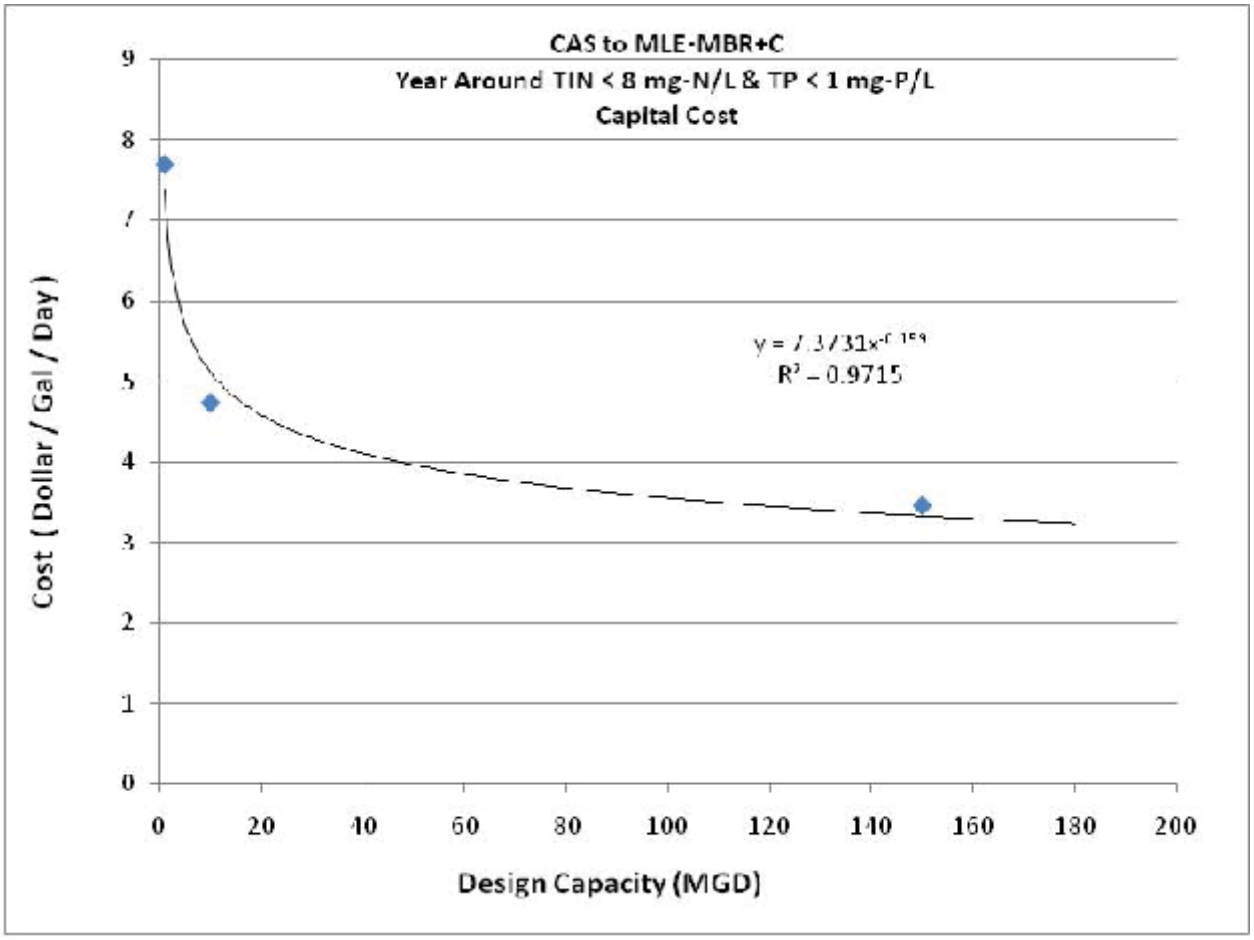


Figure 15-5. Capital Cost per Plant Capacity for CAS Plant Upgraded for Objective E Year-Round

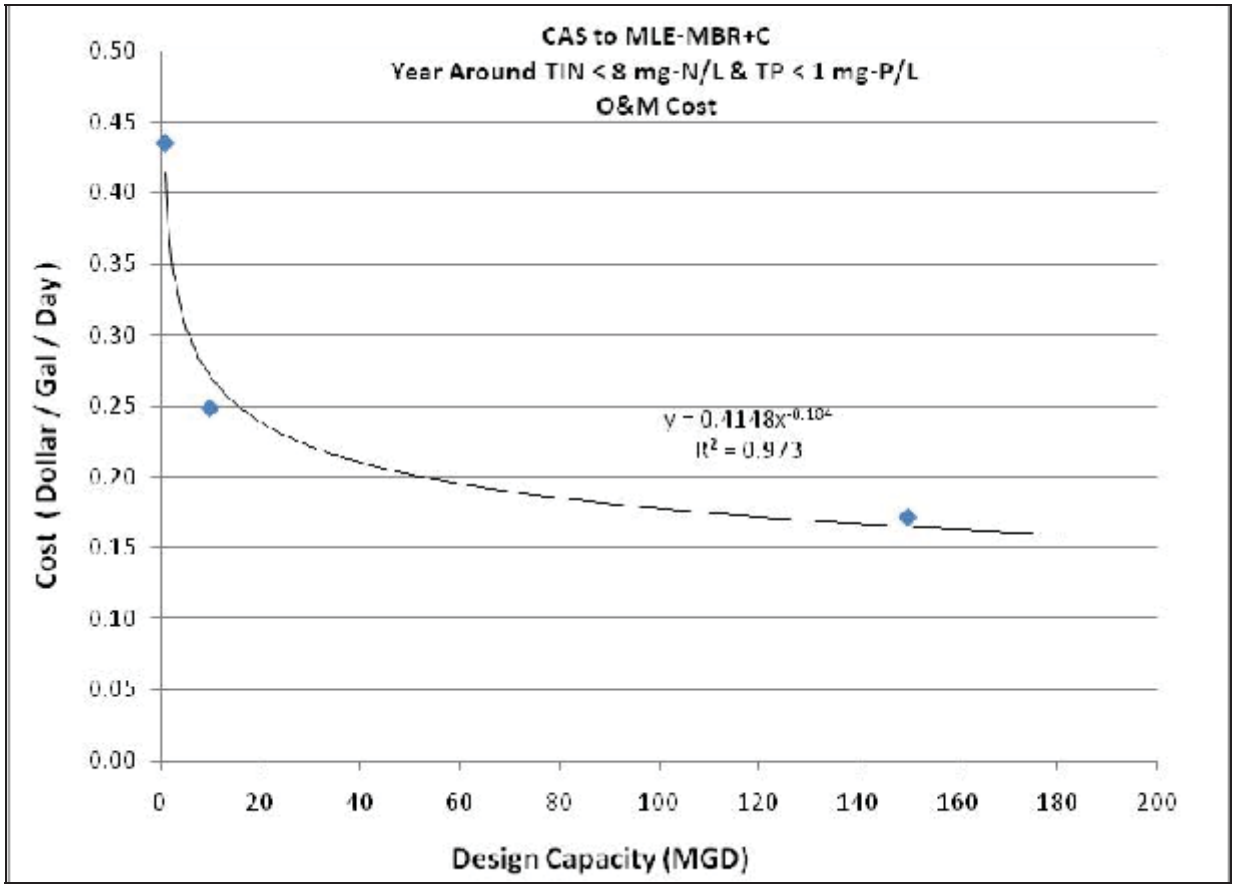


Figure 15-6. O&M Cost per Plant Capacity for CAS Plant Upgraded for Objective E Year-Round

TABLE 15-6.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE E YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$565,047	$3,472,850	$38,005,203
2014 Incremental O&M Cost	$489,775	$2,796,089	$29,003,426
Total Annual Cost	**$1,054,822**	**$6,268,939**	**$67,008,629**
Annual TIN Load Reduction (lb/yr)	35,551	355,510	5,332,650
Annual TP Load Reduction (lb/yr)	11,425	114,245	1,713,675
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$20.06	$12.73	$8.25
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$29.91	$15.26	$13.41
TIN Cost Equation:[a]			$y = 125.83x^{-0.177}$
TIN Cost R-Square Value:			0.9964
TP Cost Equation:[b]			$y = 116.06x^{-0.157}$
TP Cost R-Square Value:			0.834

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

15.1.3 Sequencing Batch Reactor Plants

Table 15-7 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective E year-round for an SBR plant. Figures 15-7 and 15-8 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 15-8 presents the annualized unit costs for reducing nutrient loads.

TABLE 16-7.
ESTIMATED COST PER CAPACITY FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE E YEAR-ROUND

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.49	$0.50	$0.23
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.10	$0.01	($0.00)

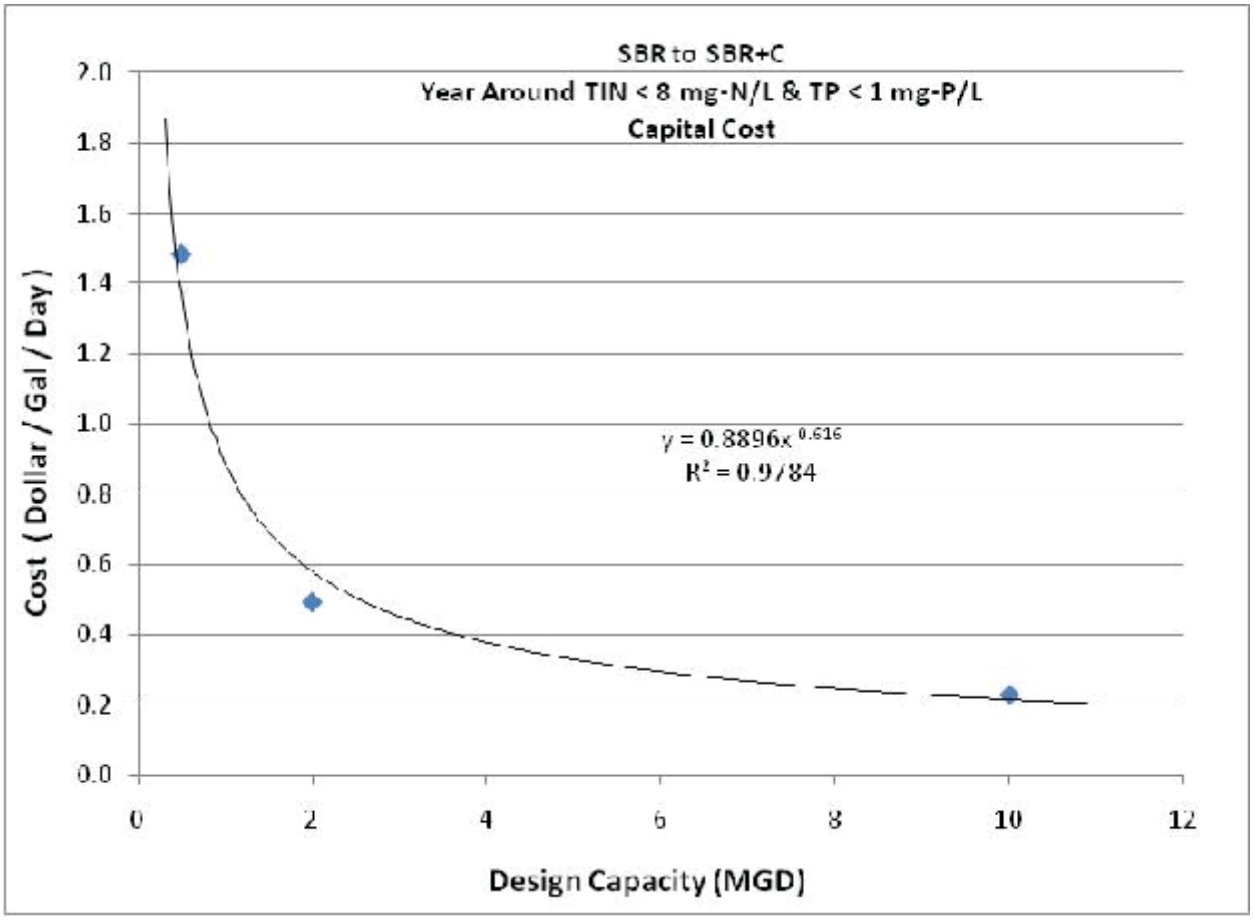


Figure 15-7. Capital Cost per Plant Capacity for SBR Plant Upgraded for Objective E Year-Round

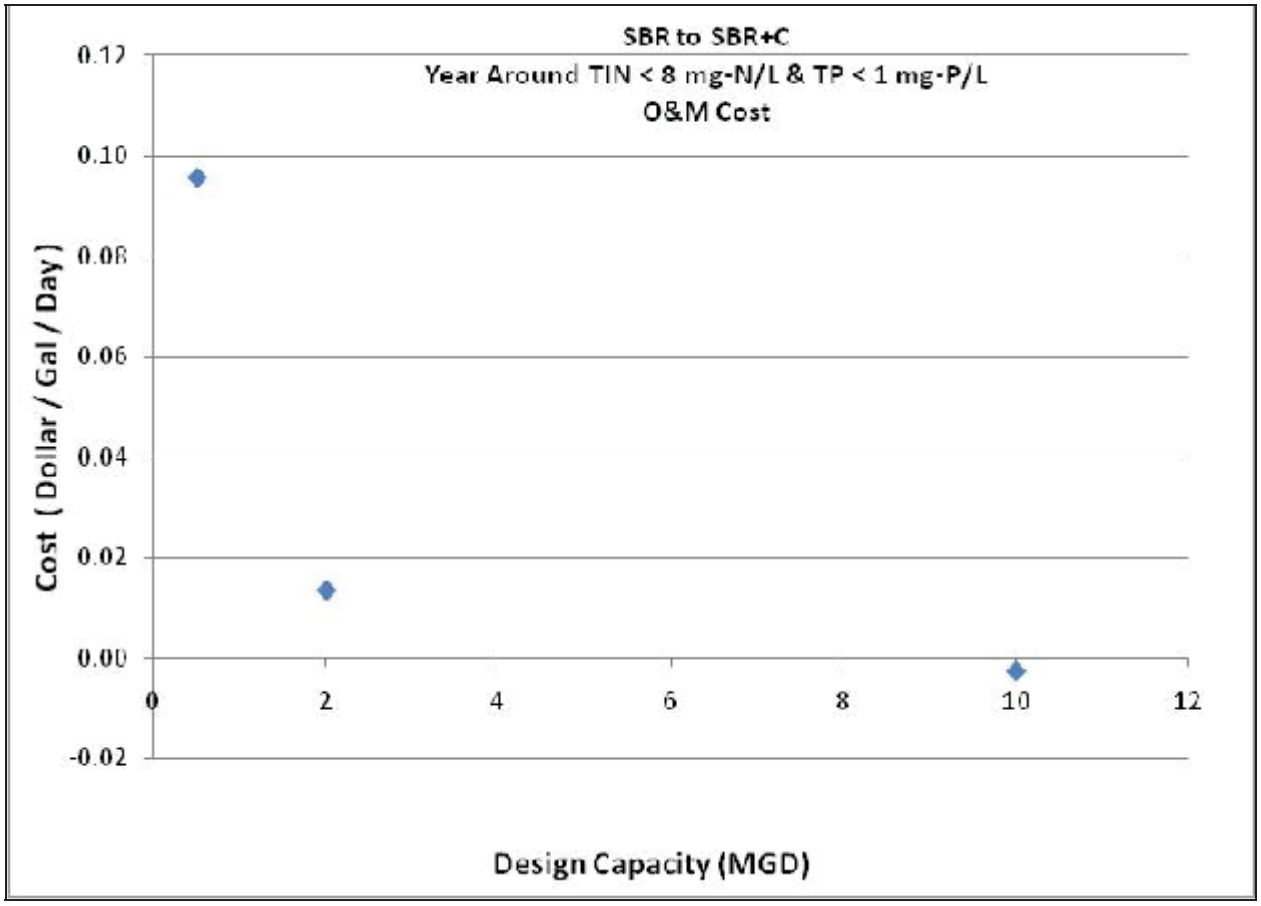


Figure 15-8. O&M Cost per Plant Capacity for SBR Plant Upgraded for Objective E Year-Round

TABLE 15-8.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE E YEAR-ROUND

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Annualized Capital Cost	$54,540	$72,740	$170,067
2014 Incremental O&M Cost	$53,878	$30,417	-$28,813
Total Annual Cost	**$1,08,418**	**$103,157**	**$141,254**
Annual TIN Load Reduction (lb/yr)	2,245	8,979	44,895
Annual TP Load Reduction (lb/yr)	2,099	8,395	41,975
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$0.21	-$0.98	-$1.79
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$51.43	$13.34	$5.28
TIN Cost Equation and R-Square Value[a]			
TP Cost Equation:[b]	$y = 14903x^{-0.755}$		
TP Cost R-Square Value:	0.9777		

a. Equation and R-square value for TIN not determined because annual cost estimates are below the level of precision that can be achieved using the CapdetWorks cost model.
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

15.1.4 Trickling Filter, Trickling Filter/Solids Contact and Rotating Biological Contactor Plants

Table 15-9 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective E year-round for a trickling filter plant. Figures 15-9 and 15-10 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 15-10 and Figures 15-11 and 15-12 summarize these costs for a trickling filter/solids contact plant. Table 15-11 and Figures 15-13 and 15-14 summarize these costs for an RBC plant. Tables 15-12, 15-13 and 15-14 present the annualized unit costs for reducing nutrient loads for TF, TF/SC and RBC plants, respectively.

TABLE 15-9.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER PLANT TO ACHIEVE OBJECTIVE E YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$9.09	$5.86	$3.69
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.50	$0.27	$0.18

TABLE 15-10.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER/SOLIDS CONTACT PLANT TO ACHIEVE OBJECTIVE E YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$7.82	$5.31	$3.37
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.37	$0.23	$0.15

TABLE 15-11.
ESTIMATED COST PER CAPACITY FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE E YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$9.10	$5.89	$3.74
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.56	$0.29	$0.19

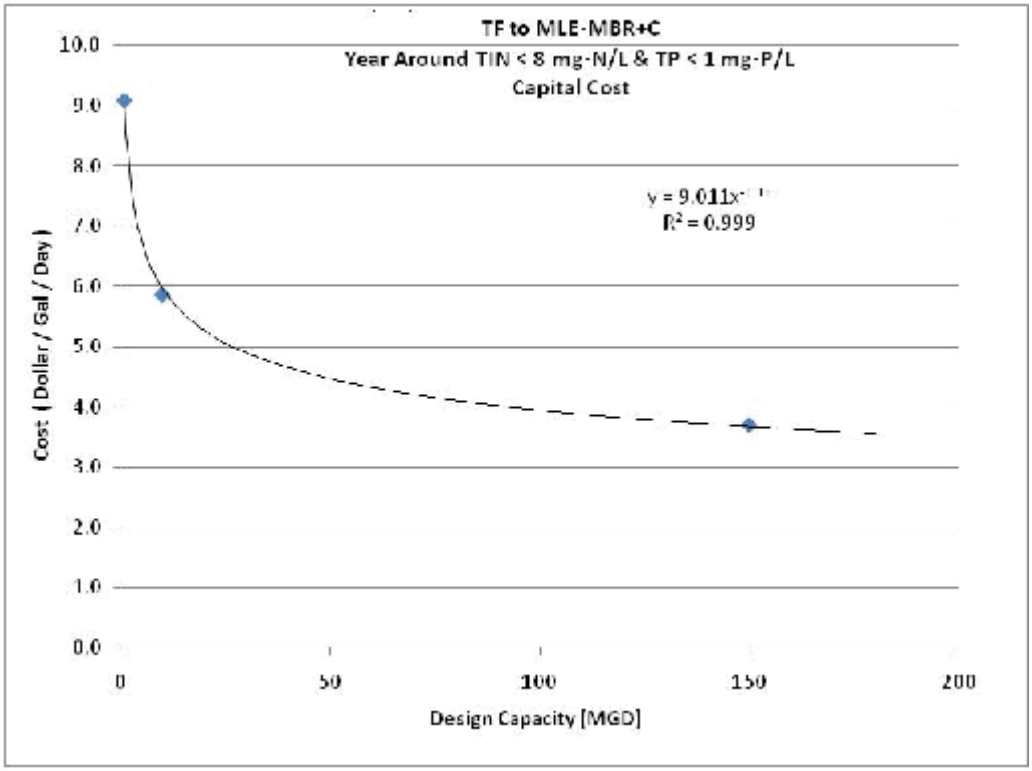


Figure 15-9. Capital Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective E Year-Round

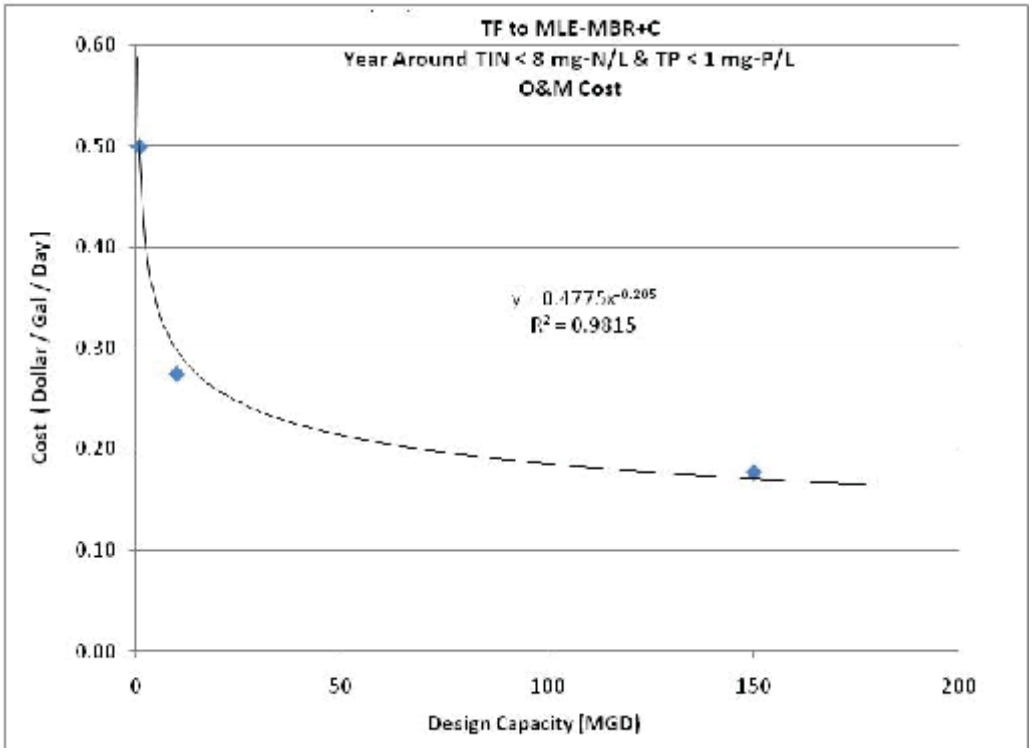


Figure 15-10. O&M Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective E Year-Round

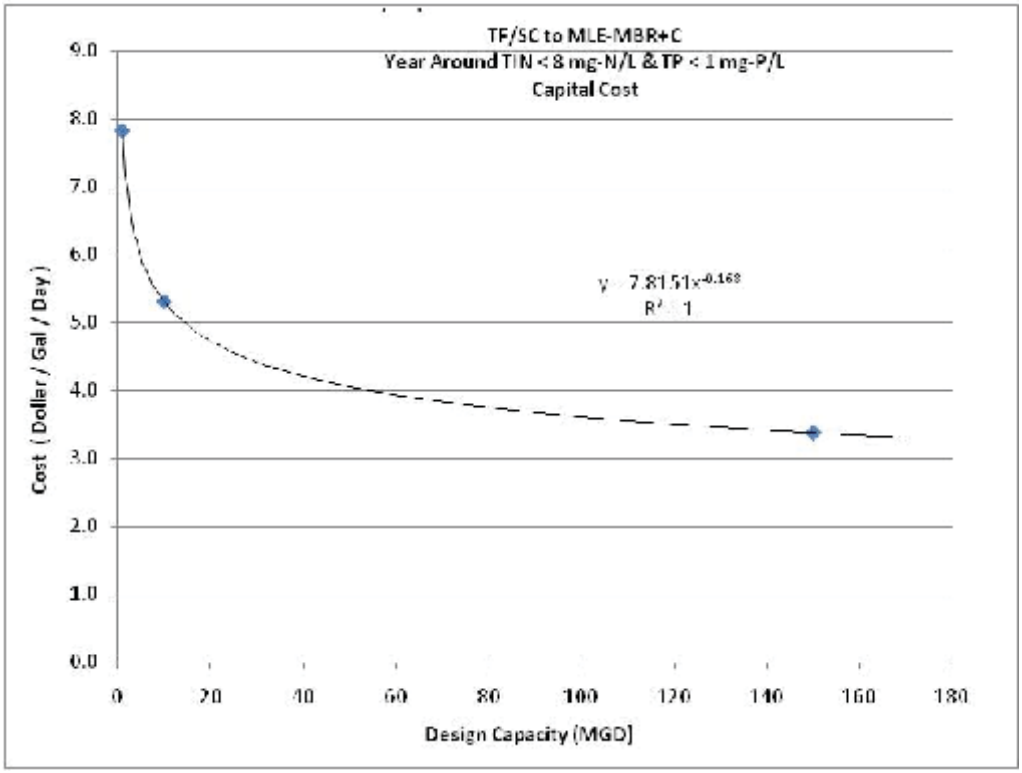


Figure 15-11. Capital Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective E Year-Round

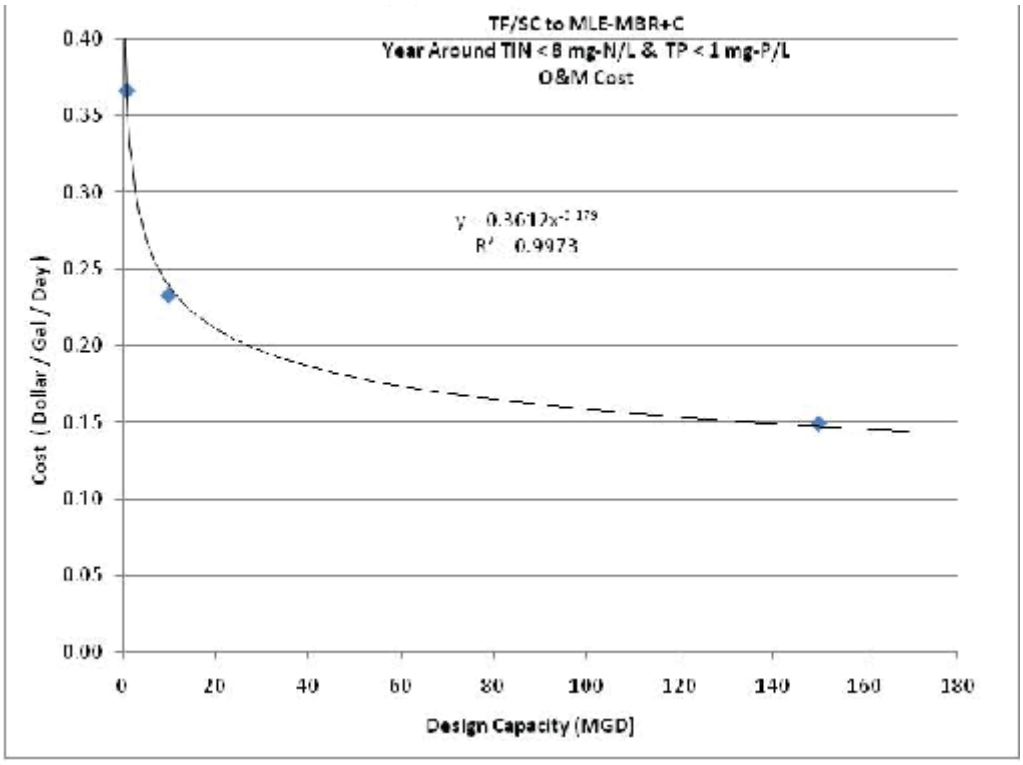


Figure 15-12. O&M Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective E Year-Round

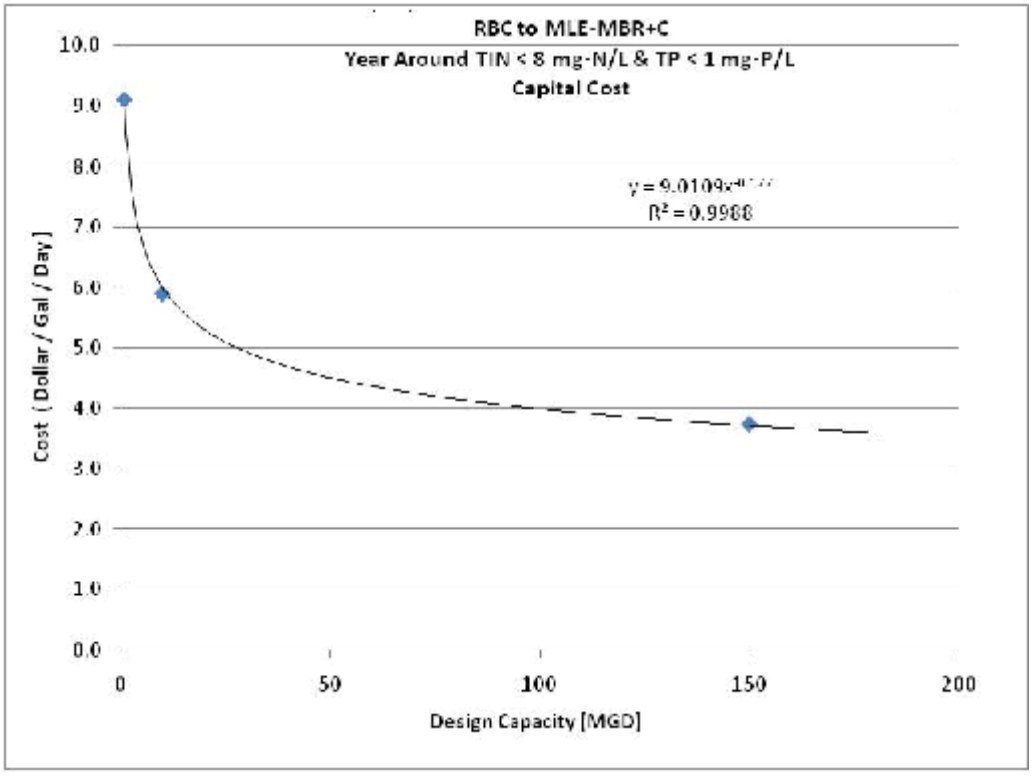


Figure 15-13. Capital Cost per Plant Capacity for RBC Upgraded for Objective E Year-Round

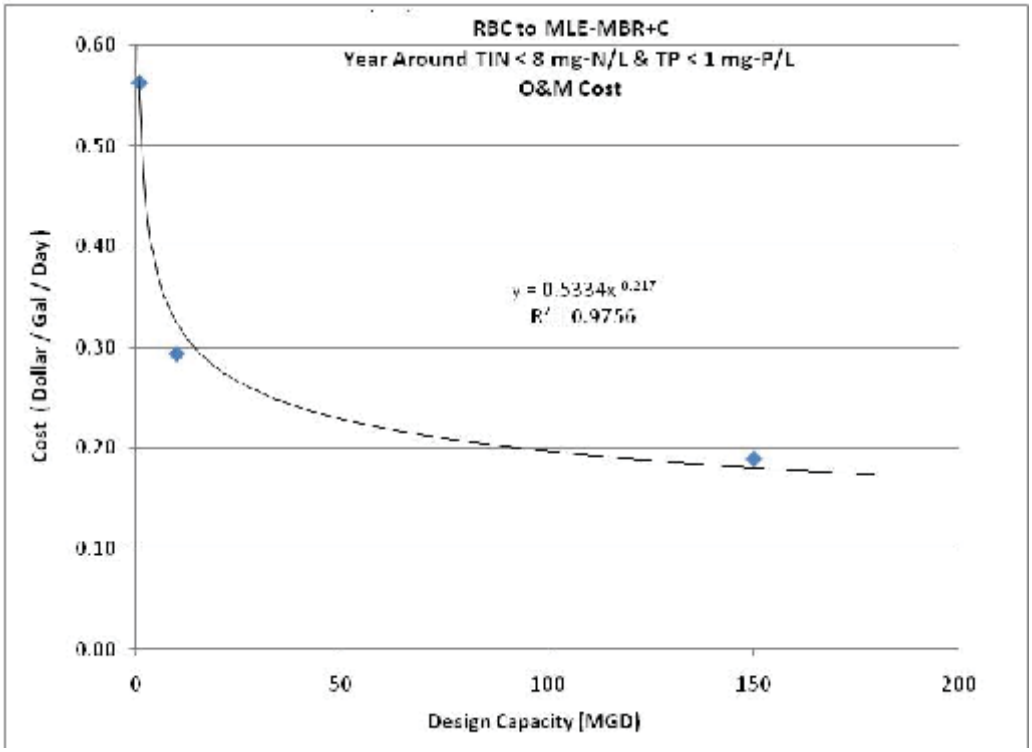


Figure 15-14. O&M Cost per Plant Capacity for RBC Plant Upgraded for Objective E Year-Round

TABLE 15-12.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TRICKLING FILTER PLANT TO ACHIEVE OBJECTIVE E YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$667,805	$4,305,835	$40,676,323
2014 Incremental O&M Cost	$561,622	$3,087,483	$29,924,655
Total Annual Cost	**$1,229,427**	**$7,392,318**	**$70,600,979**
Annual TIN Load Reduction (lb/yr)	35,551	355,510	5,332,650
Annual TP Load Reduction (lb/yr)	11,425	114,245	1,713,675
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$25.30	$16.09	$9.16
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$28.89	$14.65	$12.70
TIN Cost Equation:[a]			$y = 213.2x^{-0.203}$
TIN Cost R-Square Value:			0.9997
TP Cost Equation:[b]			$y = 62.964x^{-0.116}$
TP Cost R-Square Value:			0.9558

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 15-13.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TRICKLING FILTER/SOLIDS CONTACT PLANT TO ACHIEVE OBJECTIVE E YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$574,356	$3,896,568	$37,170,307
2014 Incremental O&M Cost	$238,822	$1,881,688	$17,690,375
Total Annual Cost	**$903,177**	**$5,888,255**	**$54,860,682**
Annual TIN Load Reduction (lb/yr)	35,551	355,510	5,332,650
Annual TP Load Reduction (lb/yr)	11,425	114,245	1,713,675
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$15.82	$11.89	$6.24
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$29.83	$14.56	$12.61
TIN Cost Equation:[a]			$y = 118.37x^{-0.187}$
TIN Cost R-Square Value:			0.9705
TP Cost Equation:[b]			$y = 128.15x^{-0.168}$
TP Cost R-Square Value:			0.8383

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 15-14.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE E YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$668,134	$4325,236	$41,200,334
2014 Incremental O&M Cost	$633,323	$3,301,949	$31,839,709
Total Annual Cost	**$1,301,457**	**$7,627,185**	**$73,040,042**
Annual TIN Load Reduction (lb/yr)	35,551	355,510	5,332,650
Annual TP Load Reduction (lb/yr)	11,425	114,245	1,713,675
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$27.16	$16.74	$9.61
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$29.40	$14.66	$12.71
TIN Cost Equation:[a]	$y = 237.79x^{-0.207}$		
TIN Cost R-Square Value:	0.9999		
TP Cost Equation:[b]	$y = 65.083x^{-0.119}$		
TP Cost R-Square Value:	0.9543		

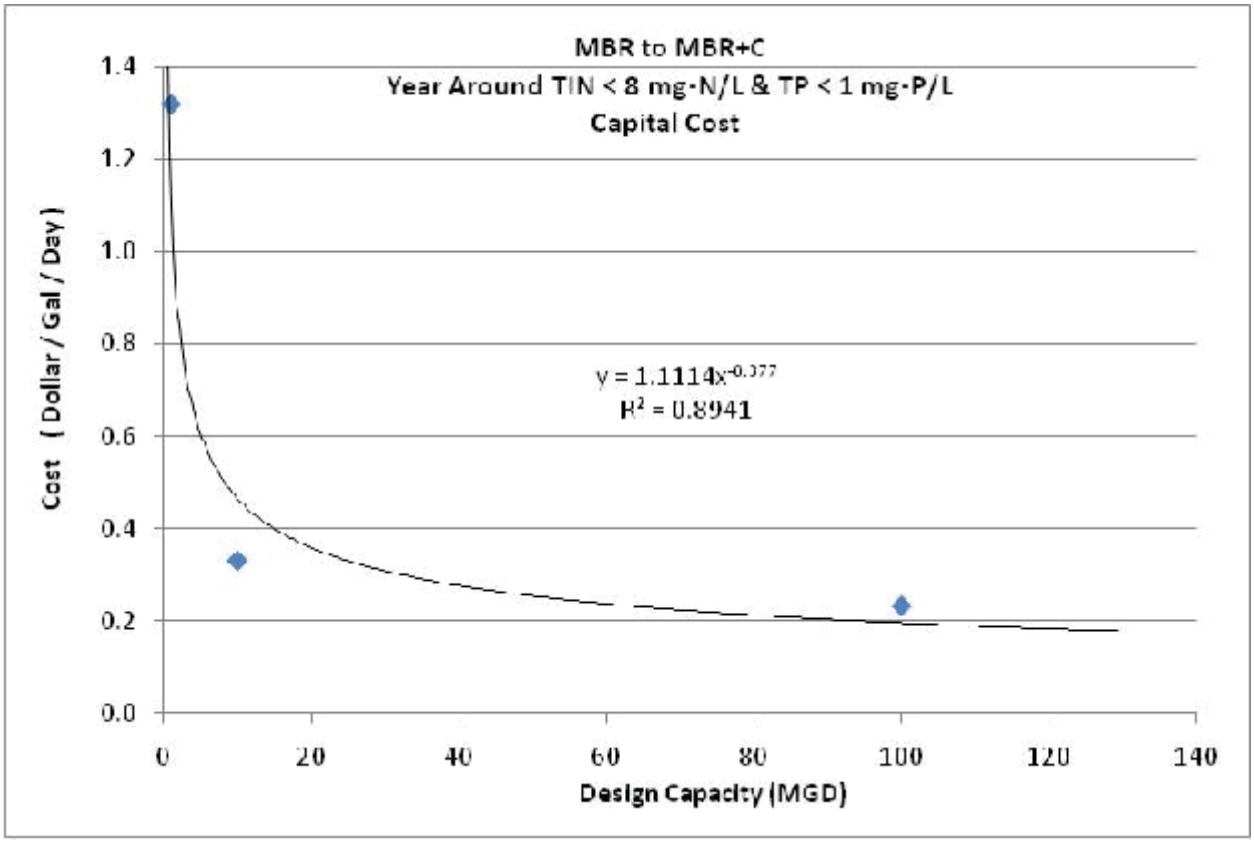
a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

15.1.5 Membrane Biological Reactor Plants

Table 15-15 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective E year-round for an MBR plant. Figures 15-15 and 15-16 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 15-16 presents the annualized unit costs for reducing nutrient loads.

TABLE 15-15.
ESTIMATED COST PER CAPACITY FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE E YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.32	$0.33	$0.23
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.16	$0.08	$0.06



15-15. Capital Cost per Plant Capacity for MBR Plant Upgraded for Objective E Year-Round

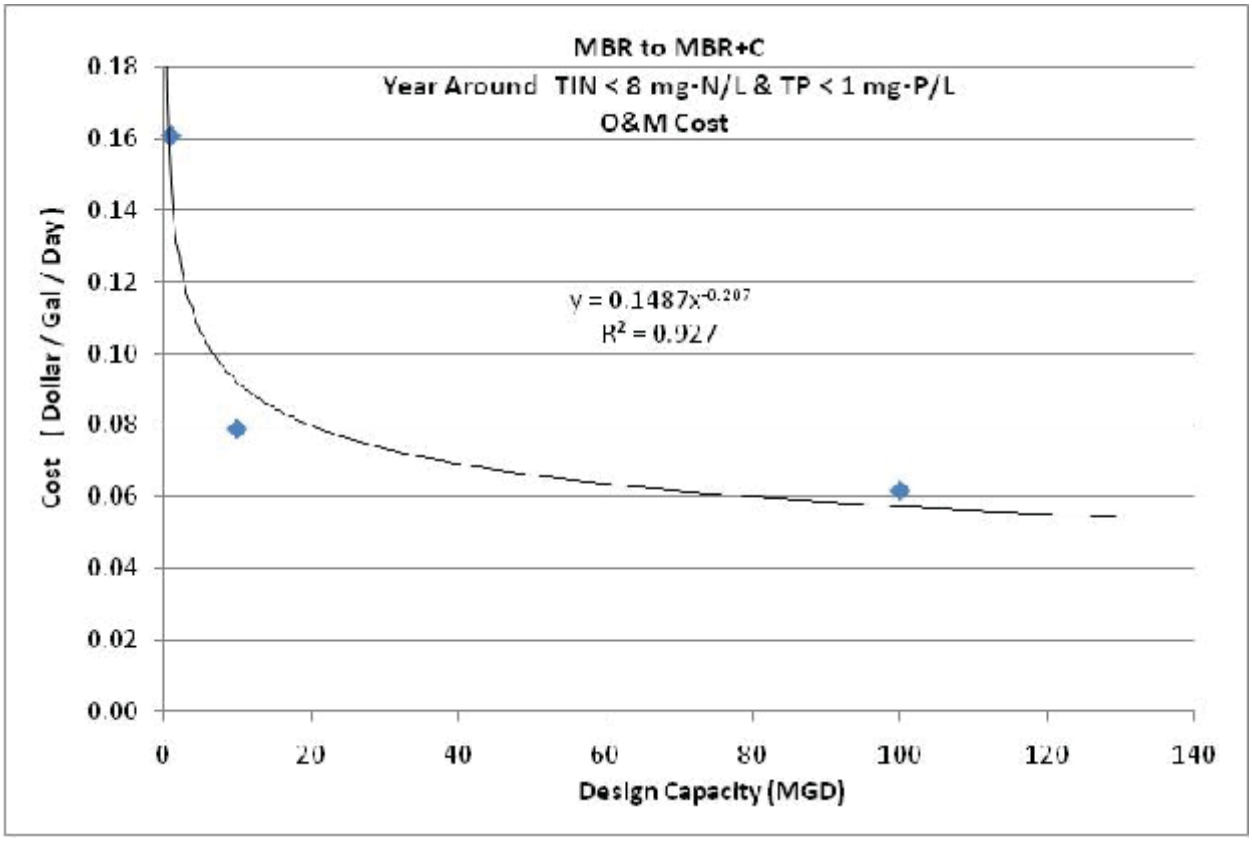


Figure 15-16. O&M Cost per Plant Capacity for MBR Plant Upgraded for Objective E Year-Round

TABLE 15-16.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE E YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$97,008	$242,560	$1,707,918
2014 Incremental O&M Cost	$180,864	$889,546	$6,960,248
Total Annual Cost	**$277,871**	**$1,132,106**	**$8,668,166**
Annual TIN Load Reduction (lb/yr)	0	0	0
Annual TP Load Reduction (lb/yr)	10,768	107,675	1,076,750
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	0	0	0
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$25.81	$10.51	$8.05
TIN Cost Equation:[a]			—
TIN Cost R-Square Value:			—
TP Cost Equation:[b]			$y = 243.32x^{-0.253}$
TP Cost R-Square Value:			0.9107

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

15.1.6 High-Purity Oxygen Activated Sludge Plants

High-purity oxygen activated sludge plants were not evaluated for any objectives that include phosphorus removal, so no costs associated with Objective E were developed for these plants.

15.1.7 Aerated or Facultative Lagoon Plants

Table 15-17 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective E year-round for an aerated lagoon plant. Figures 15-17 and 15-18 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 15-18 and Figures 15-19 and 15-20 summarize these costs for a facultative lagoon plant. Tables 15-19 and 15-20 present the annualized unit costs for reducing nutrient loads for aerated lagoon and facultative lagoon plants, respectively.

TABLE 15-17.
ESTIMATED COST PER CAPACITY FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE E YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$24.70	$18.27	$11.64	$7.27
Incremental Annual O&M Cost per gpd of Plant Capacity	$1.21	$0.75	$0.38	$0.24

TABLE 15-18.
ESTIMATED COST PER CAPACITY FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE E YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$24.56	$18.15	$11.55	$7.22
Incremental Annual O&M Cost per gpd of Plant Capacity	$1.49	$0.98	$0.54	$0.28

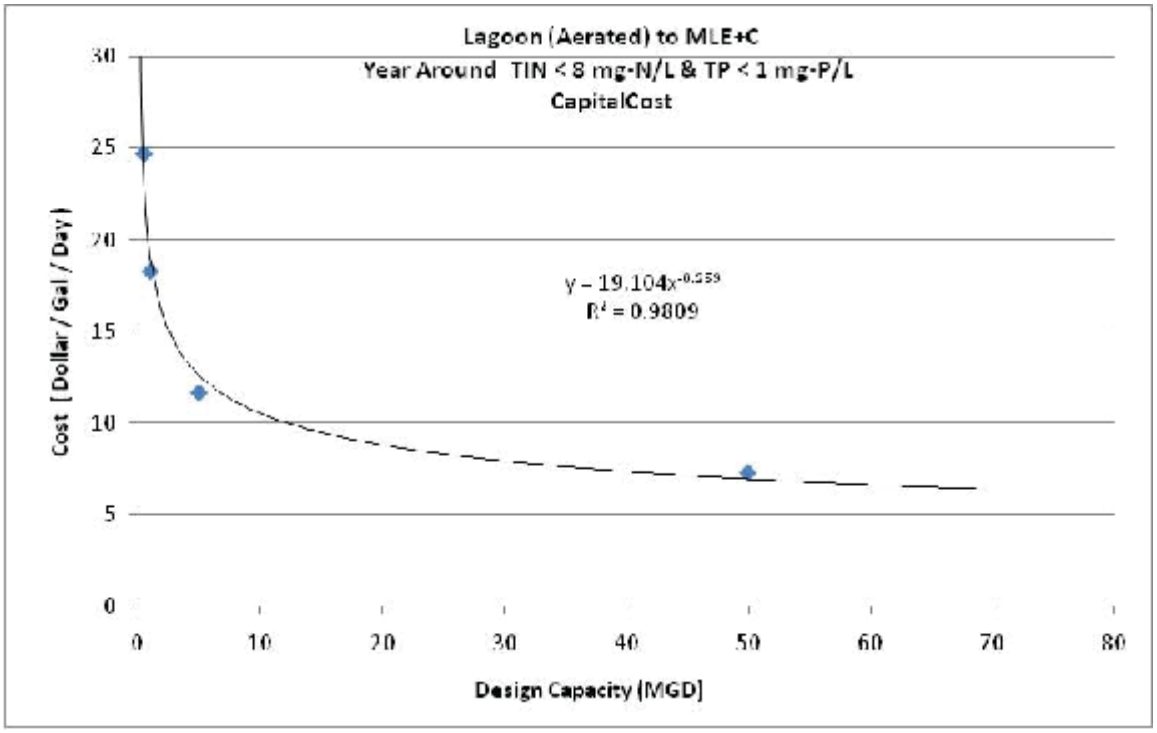


Figure 15-17. Capital Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective E Year-Round

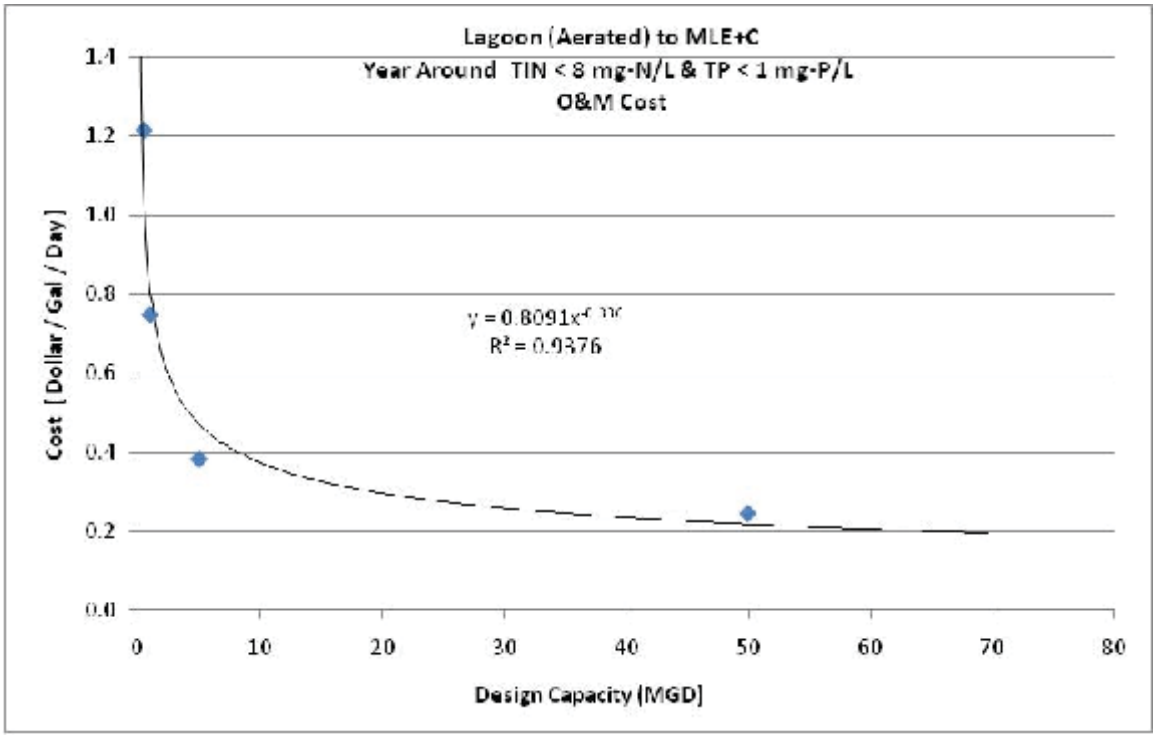


Figure 15-18. O&M Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective E Year-Round

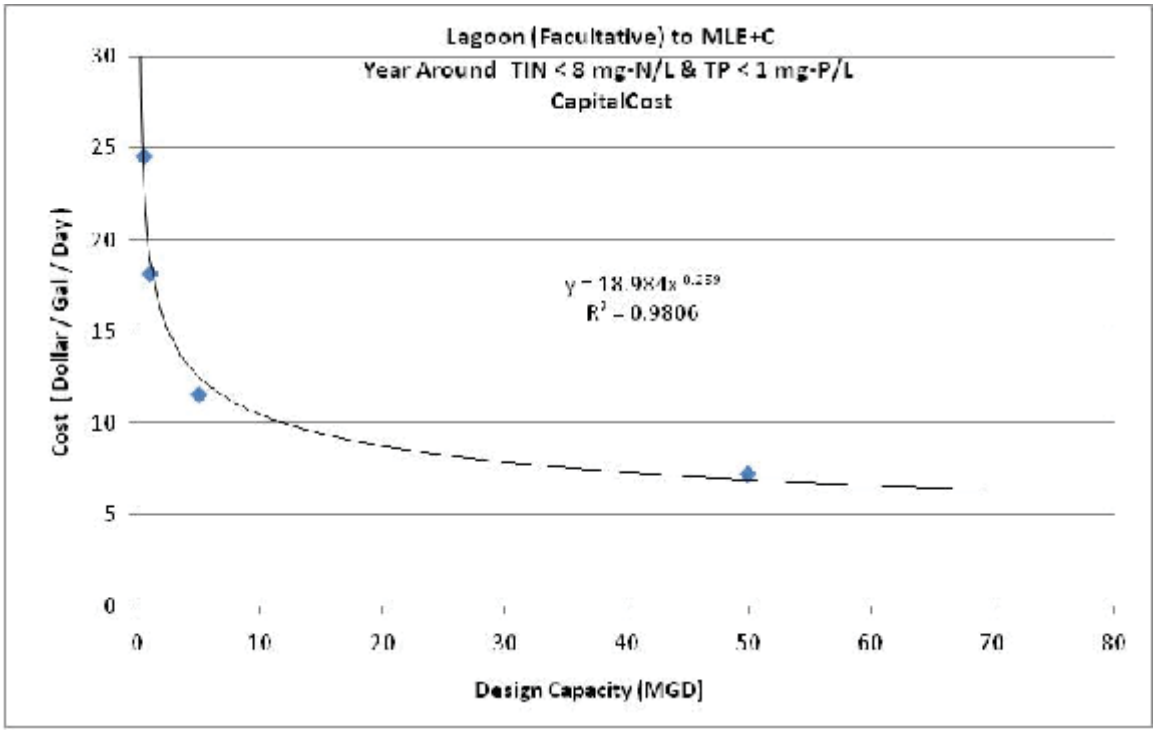


Figure 15-19. Capital Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective E Year-Round

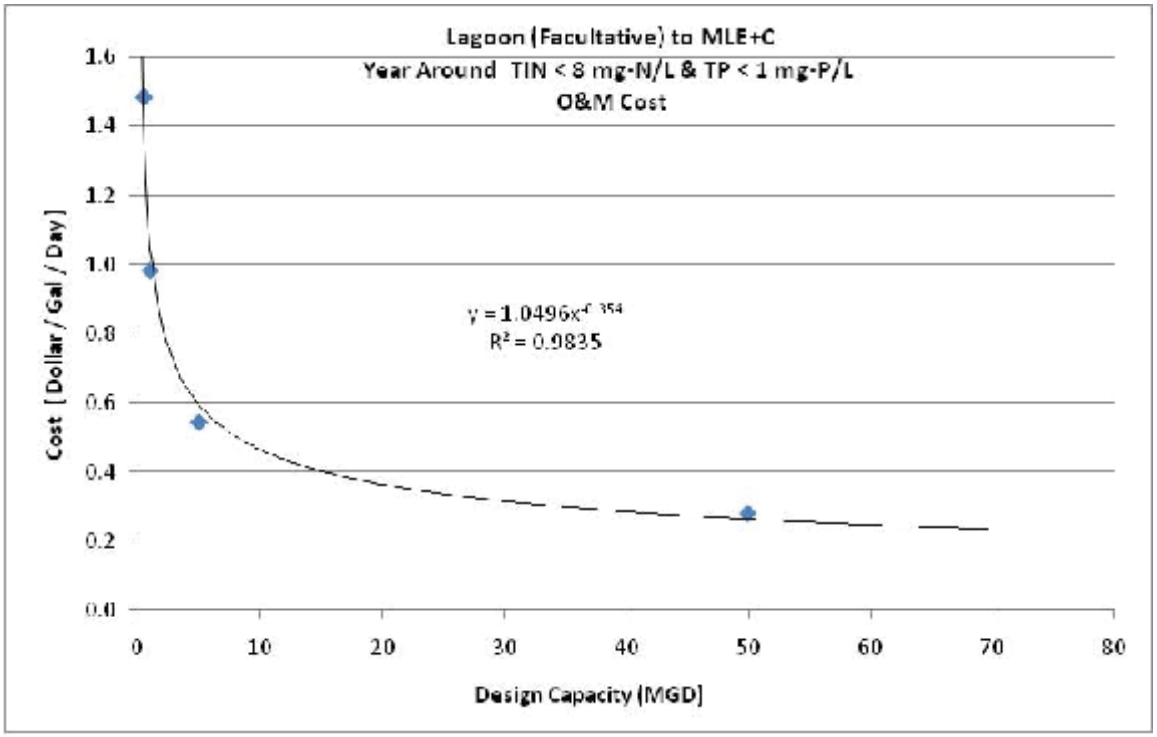


Figure 15-20. O&M Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective E Year-Round

TABLE 15-19.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE E YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$906,931	$1,341,831	$4,275,806	$26,699,852
2014 Incremental O&M Cost	$682,841	$841,183	$2,149,969	$13,773,921
Total Annual Cost	**$1,589,771**	**$2,183,013**	**$6,425,775**	**$40,473,772**
Annual TIN Load Reduction (lb/yr)	17,684	35,369	176,843	1,759,300
Annual TP Load Reduction (lb/yr)	5,712	11,425	57,123	571,225
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$69.34	$47.28	$29.03	$16.54
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$63.65	$44.70	$22.61	$19.91
TIN Cost Equation:[a]	$y = 1183.4x^{-0.3}$			
TIN Cost R-Square Value:	0.9791			
TP Cost Equation:[b]	$y = 469.06x^{-0.25}$			
TP Cost R-Square Value:	0.8503			

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 15-20.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE E YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$901,913	$1,333,358	$4,242,654	$26,525,456
2014 Incremental O&M Cost	$836,010	$1,104,861	$3,052,796	$15,661,191
Total Annual Cost	**$1,737,923**	**$2,438,219**	**$7,295,450**	**$42,186,646**
Annual TIN Load Reduction (lb/yr)	17,684	35,369	176,843	1,759,300
Annual TP Load Reduction (lb/yr)	5,712	11,425	57,123	571,225
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$77.64	$54.48	$33.96	$17.49
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$63.89	$44.77	$22.59	$20.00
TIN Cost Equation:[a]	$y = 1560.9x^{-0.314}$			
TIN Cost R-Square Value:	0.9911			
TP Cost Equation:[b]	$y = 469x^{-0.25}$			
TP Cost R-Square Value:	0.8472			

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

15.2 SEASONAL NUTRIENT REMOVAL

15.2.1 Extended Aeration Plants

Table 15-21 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective E seasonally for an extended aeration plant using mechanical aeration. Figures 15-21 and 15-22 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 15-22 and Figures 15-23 and 15-24 summarize these costs for an extended aeration plant using diffuser aeration. Tables 15-23 and 15-24 present the annualized unit costs for reducing nutrient loads for mechanical aeration and diffuser aeration plants, respectively.

TABLE 15-21.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE E SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$5.41	$2.41	$2.37
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.38	$0.12	$0.07

TABLE 15-22.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE E SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.68	$0.92	$0.50
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.19	$0.06	$0.04

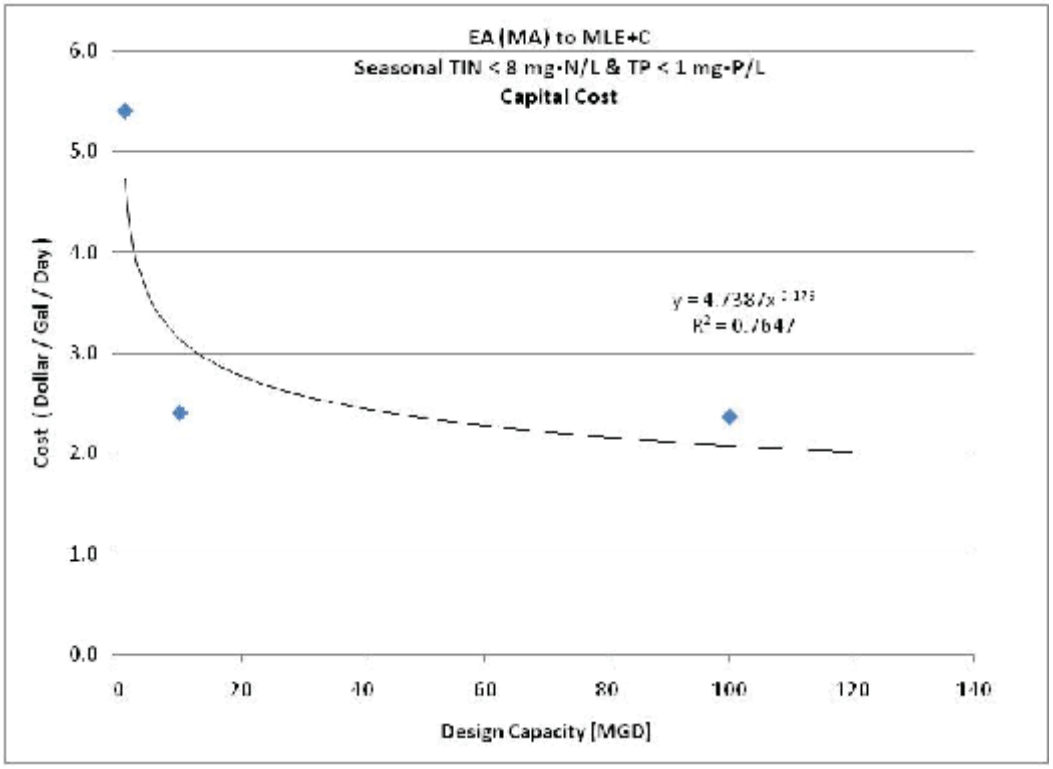


Figure 15-21. Capital Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective E Seasonally

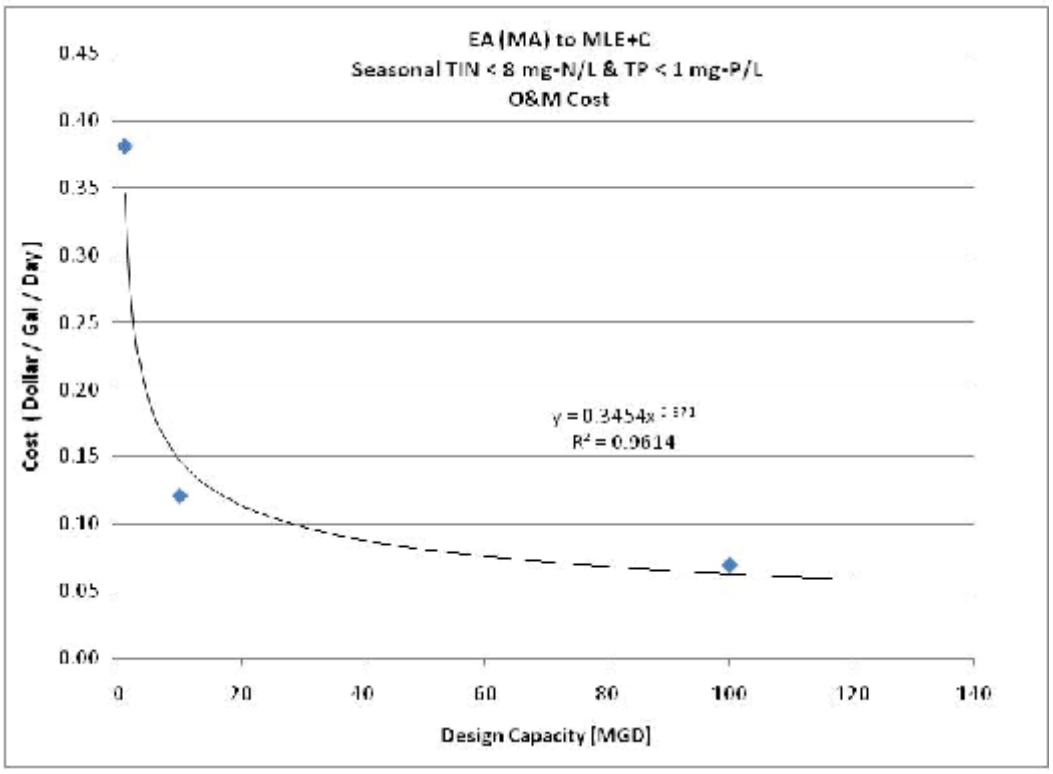


Figure 15-22. O&M Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective E Seasonal

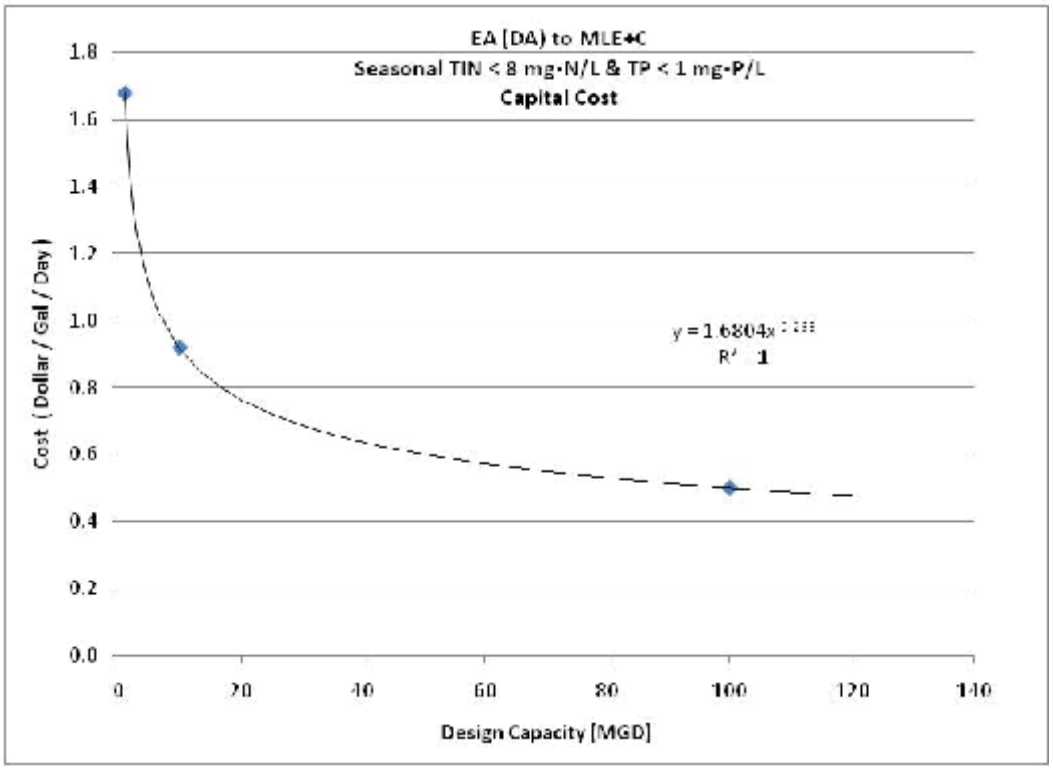


Figure 15-23. Capital Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective E Seasonally

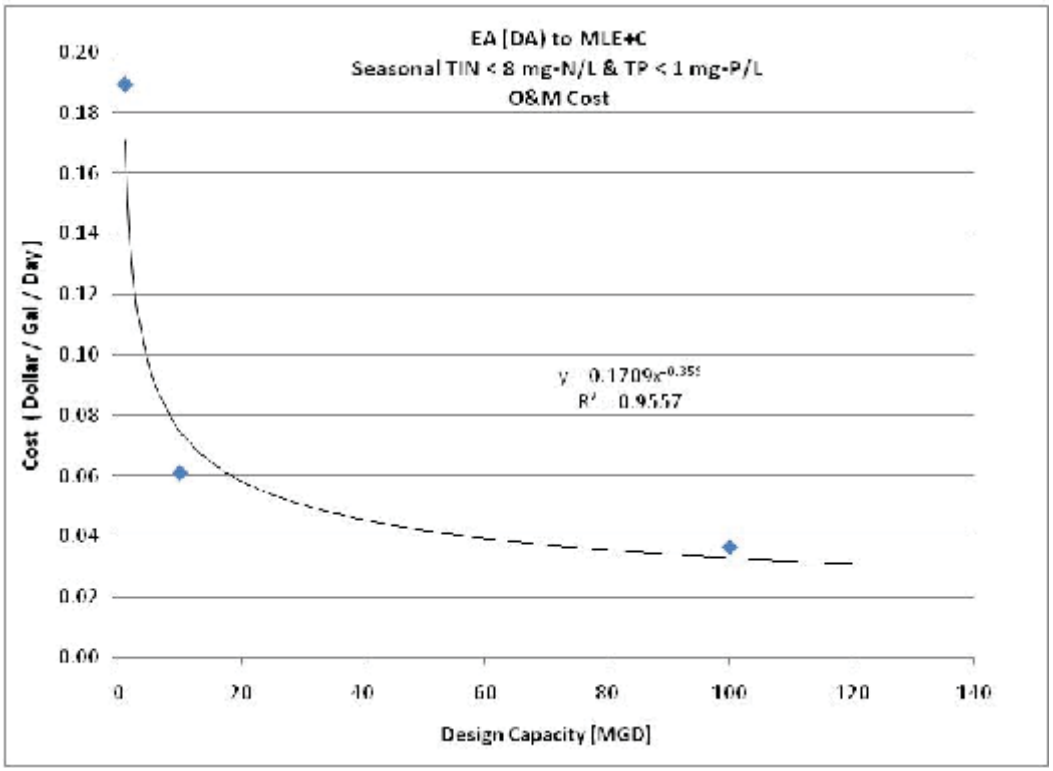


Figure 15-24. O&M Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective E Seasonal

TABLE 15-23.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EA (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE E SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$387,213	$1,769,044	$17,407,459
2014 Incremental O&M Cost	$429,157	$1,358,917	$7,782,443
Total Annual Cost	**$826,370**	**$3,127,961**	**$25,189,902**
Annual TIN Load Reduction (lb/yr)	19,564	195,640	1,956,400
Annual TP Load Reduction (lb/yr)	5,694	56940	569,400
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$32.40	$10.66	$8.34
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$33.79	$18.32	$15.58
TIN Cost Equation:[a]			$y = 515.81x^{-0.295}$
TIN Cost R-Square Value:			0.8804
TP Cost Equation:[b]			$y = 134.13x^{-0.168}$
TP Cost R-Square Value:			0.8987

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 15-24.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EA ((DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE E SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$123,280	$674,956	$3,669,667
2014 Incremental O&M Cost	$213,115	$685,525	$4,083,459
Total Annual Cost	**$336,395**	**$1,360,481**	**$7,753,125**
Annual TIN Load Reduction (lb/yr)	19,546	195,458	1,954,575
Annual TP Load Reduction (lb/yr)	5,694	56940	569400
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$7.21	$1.44	$0.05
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$34.32	$18.95	$13.44
TIN Cost Equation:[a]			$y = 412014x^{-1.079}$
TIN Cost R-Square Value:			0.9603
TP Cost Equation:[b]			$y = 191.4x^{-0.204}$
TP Cost R-Square Value:			0.9768

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

15.2.2 Conventional Activated Sludge Plants

Table 15-25 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective E seasonally for a conventional activated sludge plant. Figures 15-25 and 15-26 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 15-26 presents the annualized unit costs for reducing nutrient loads.

TABLE 15-25.
ESTIMATED COST PER CAPACITY FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE E SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$3.34	$1.35	$1.54
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.34	$0.14	$0.09

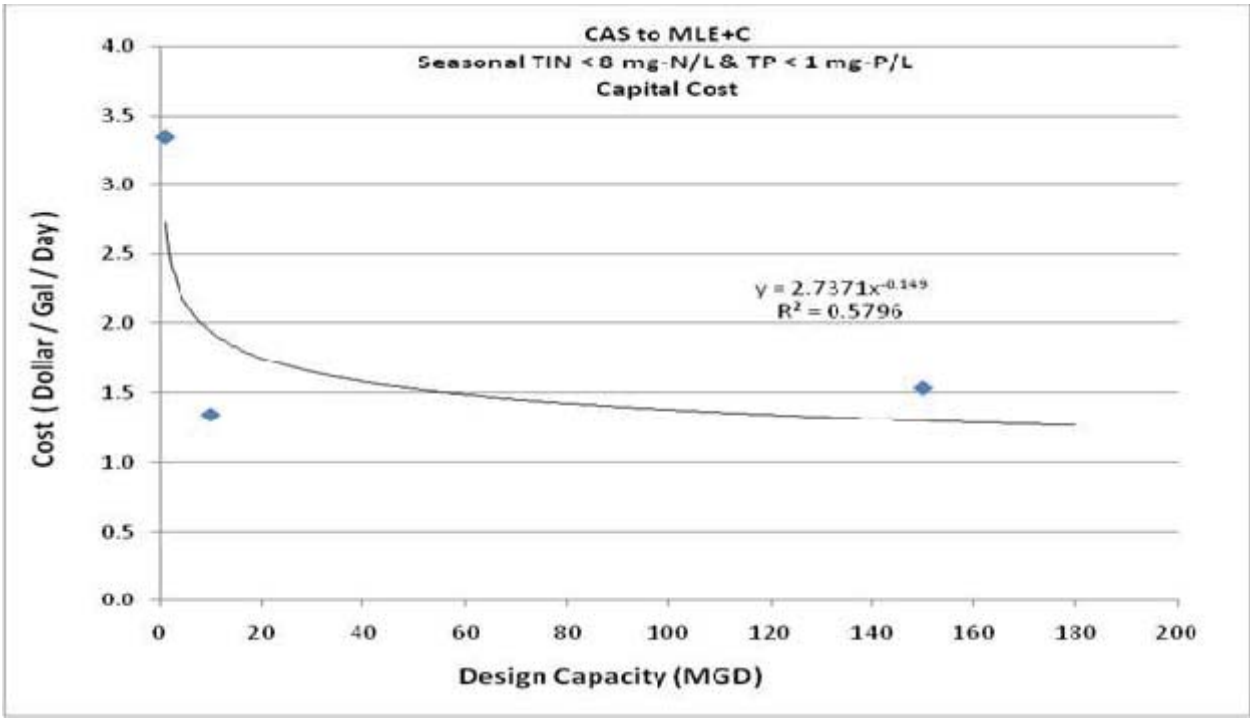


Figure 15-25. Capital Cost per Plant Capacity for CAS Plant Upgraded for Objective E Seasonally

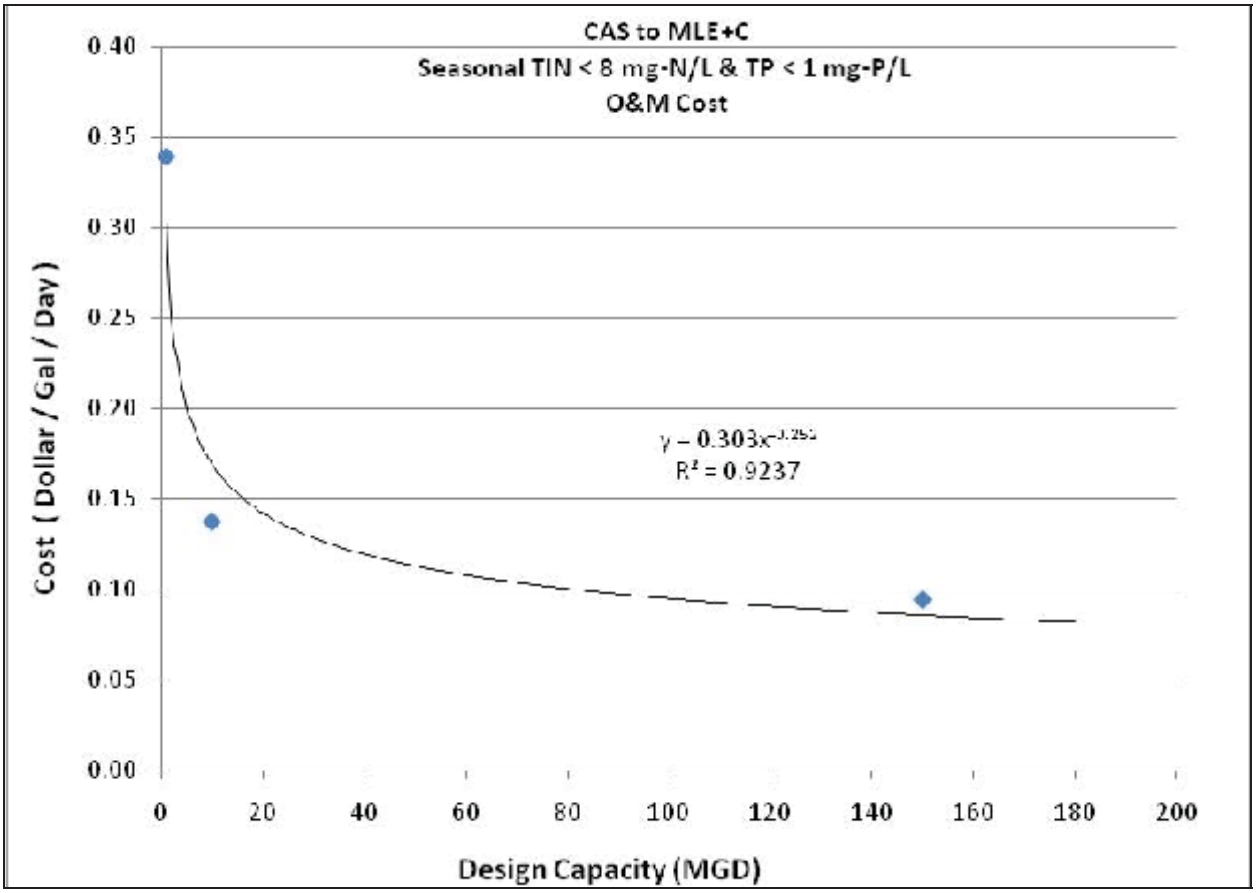


Figure 15-26. O&M Cost per Plant Capacity for CAS Plant Upgraded for Objective E Seasonal

TABLE 15-26.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE E SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$245,137	$988,465	$16,923,854
2014 Incremental O&M Cost	$381,947	$1,546,730	$15,914,019
Total Annual Cost	**$627,084**	**$2,535,196**	**$32,837,873**
Annual TIN Load Reduction (lb/yr)	19,418	194,180	2,912,700
Annual TP Load Reduction (lb/yr)	5,895	58,948	884,213
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$15.94	$5.77	$5.00
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$53.86	$24.01	$20.66
TIN Cost Equation:[a]			$y = 125.02x^{-0.226}$
TIN Cost R-Square Value:			0.8055
TP Cost Equation:[b]			$y = 239.89x^{-0.187}$
TP Cost R-Square Value:			0.8308

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

15.2.3 Sequencing Batch Reactor Plants

Table 15-27 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective E seasonally for an SBR plant. Figures 15-27 and 15-28 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 15-28 presents the annualized unit costs for reducing nutrient loads.

TABLE 15-27.
ESTIMATED COST PER CAPACITY FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE E SEASONALLY

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.46	$0.48	$0.21
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.09	$0.02	$0.01

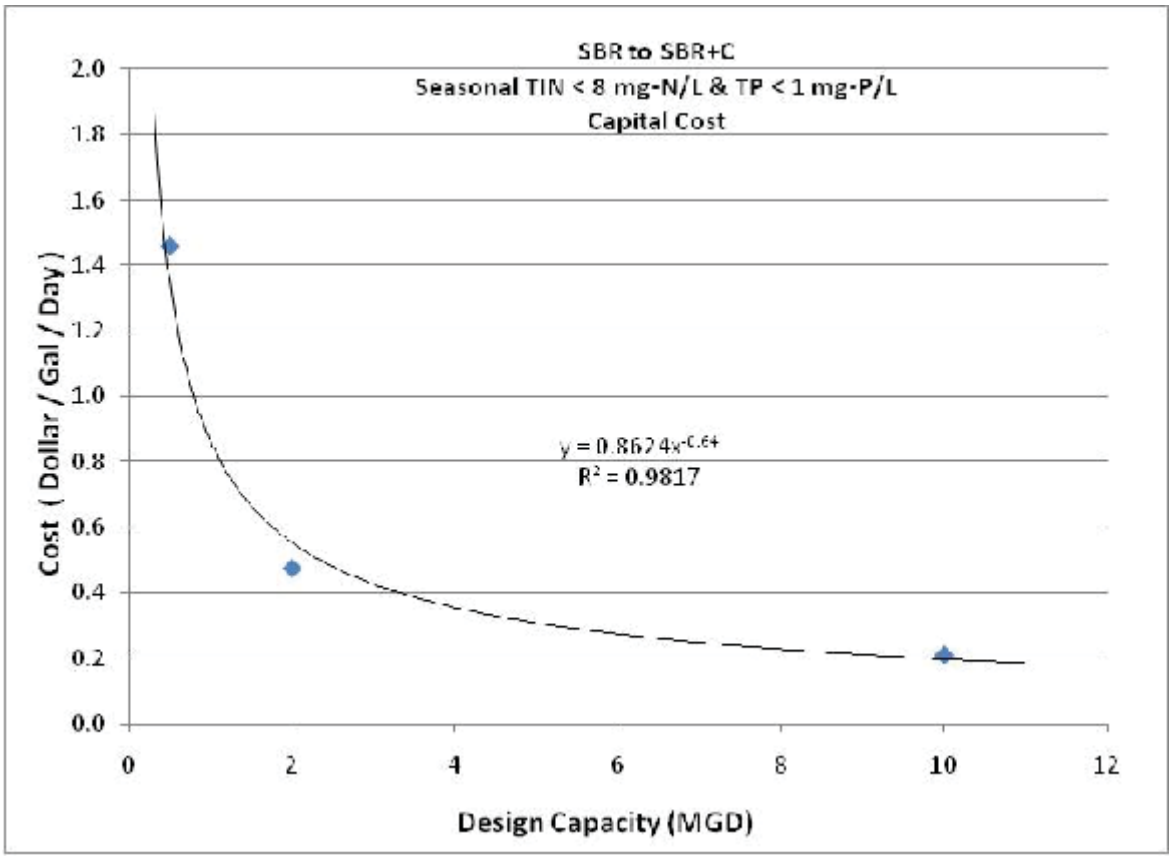


Figure 15-27. Capital Cost per Plant Capacity for SBR Plant Upgraded for Objective E Seasonally

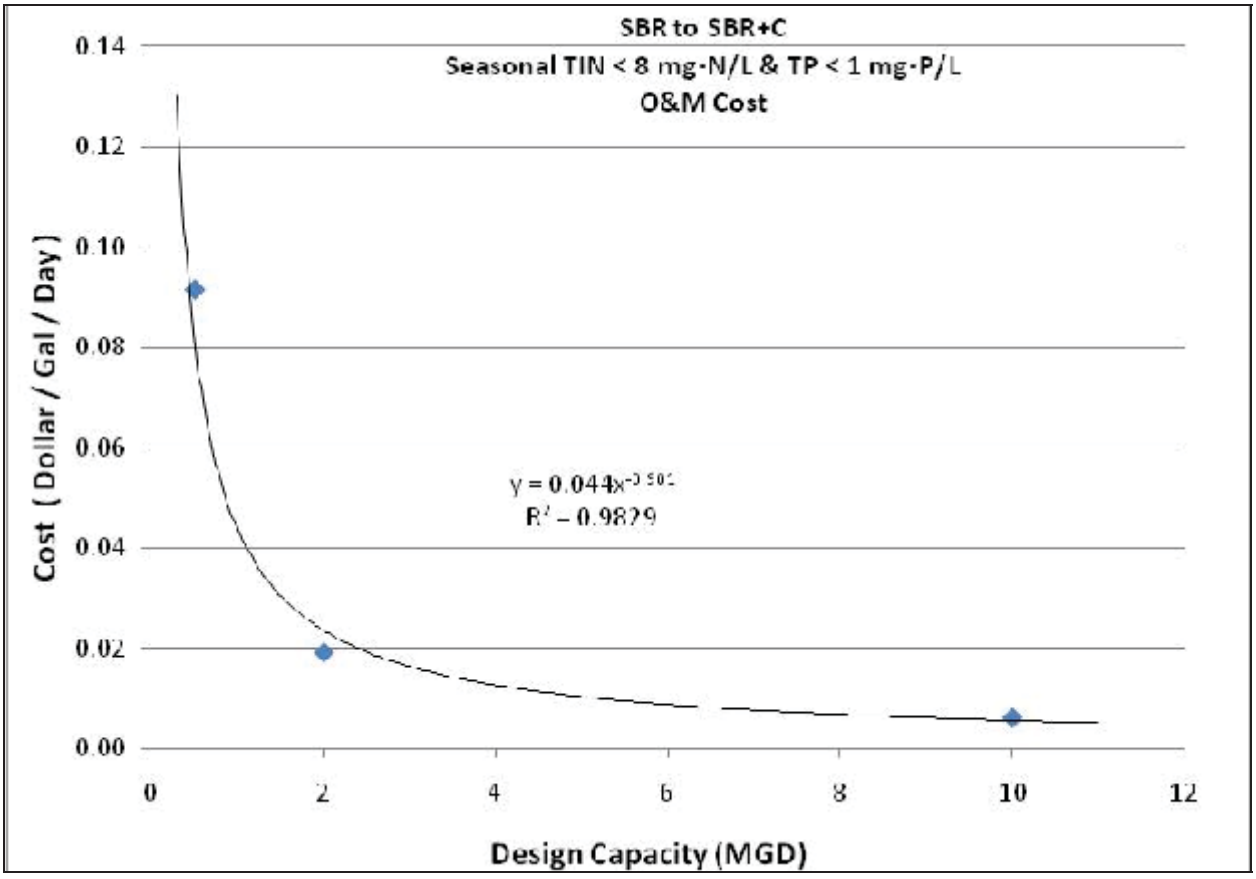


Figure 15-28. O&M Cost per Plant Capacity for SBR Plant Upgraded for Objective E Seasonal

TABLE 15-28.
UNIT NUTRIENT REMOVAL COSTS FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE E SEASONALLY

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Annualized Capital Cost	$53,512	$69,913	$155,671
2014 Incremental O&M Cost	$51,605	$43,163	$68,421
Total Annual Cost	**$105,116**	**$113,076**	**$224,102**
Annual TIN Load Reduction (lb/yr)	246	986	4,928
Annual TP Load Reduction (lb/yr)	1,141	4,563	22,813
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$0.21	-$13.04	-$9.46
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$91.39	$27.60	$11.87
TIN Cost Equation and R-Square Value[a]			
TP Cost Equation:[b]	$y = 9820.1x^{-0.677}$		
TP Cost R-Square Value:	0.9798		

a. Equation and R-square value for TIN not determined because annual cost estimates are below the level of precision that can be achieved using the CapdetWorks cost model.
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

15.2.4 Trickling Filter, Trickling Filter/Solids Contact and Rotating Biological Contactor Plants

Table 15-29 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective E seasonally for a trickling filter plant. Figures 15-29 and 15-30 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 15-30 and Figures 15-31 and 15-32 summarize these costs for a trickling filter/solids contact plant. Table 15-31 and Figures 15-33 and 15-34 summarize these costs for an RBC plant. Tables 15-32, 15-33 and 15-34 present the annualized unit costs for reducing nutrient loads for TF, TF/SC and RBC plants, respectively.

TABLE 15-29.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER PLANT TO ACHIEVE OBJECTIVE E SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$5.39	$2.88	$2.03
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.40	$0.16	$0.10

TABLE 15-30.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER/SOLIDS CONTACT PLANT TO ACHIEVE OBJECTIVE E SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$3.65	$2.19	$1.62
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.27	$0.12	$0.07

TABLE 15-31.
ESTIMATED COST PER CAPACITY FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE E SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$5.41	$2.90	$2.08
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.47	$0.18	$0.11

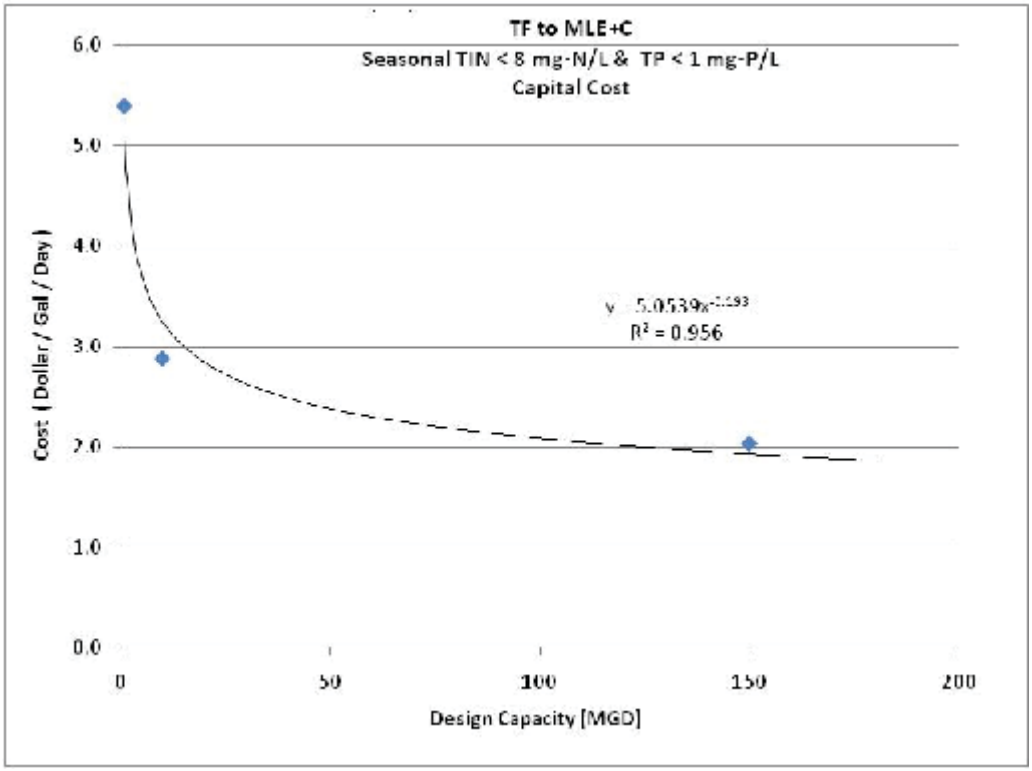


Figure 15-29. Capital Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective E Seasonally

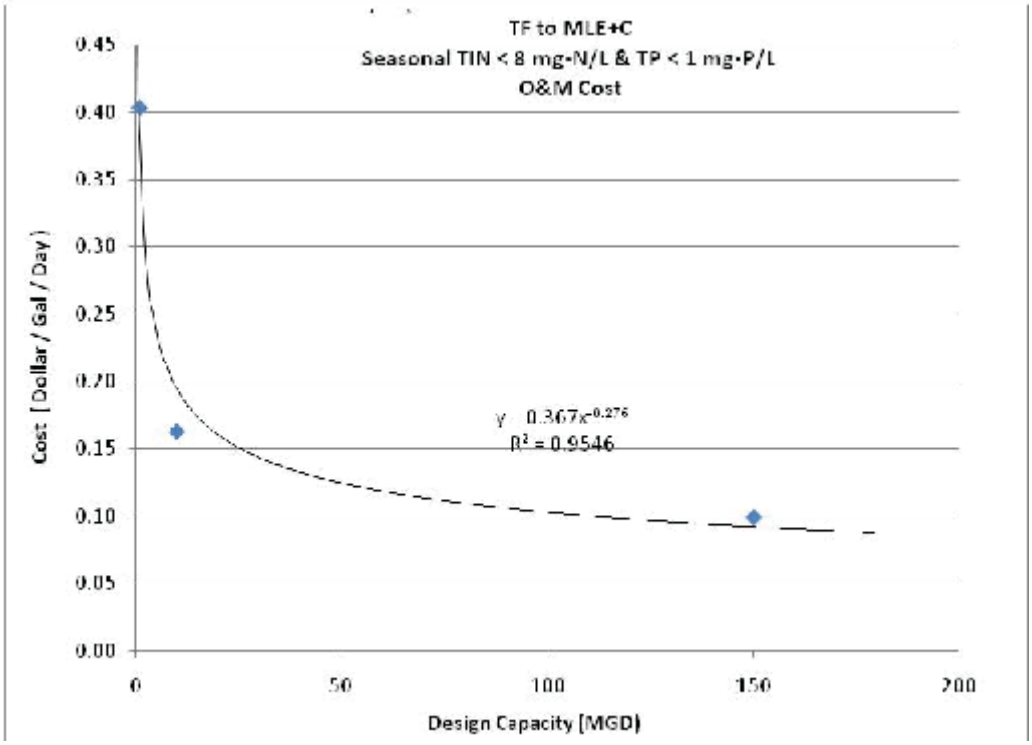


Figure 15-30. O&M Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective E Seasonal

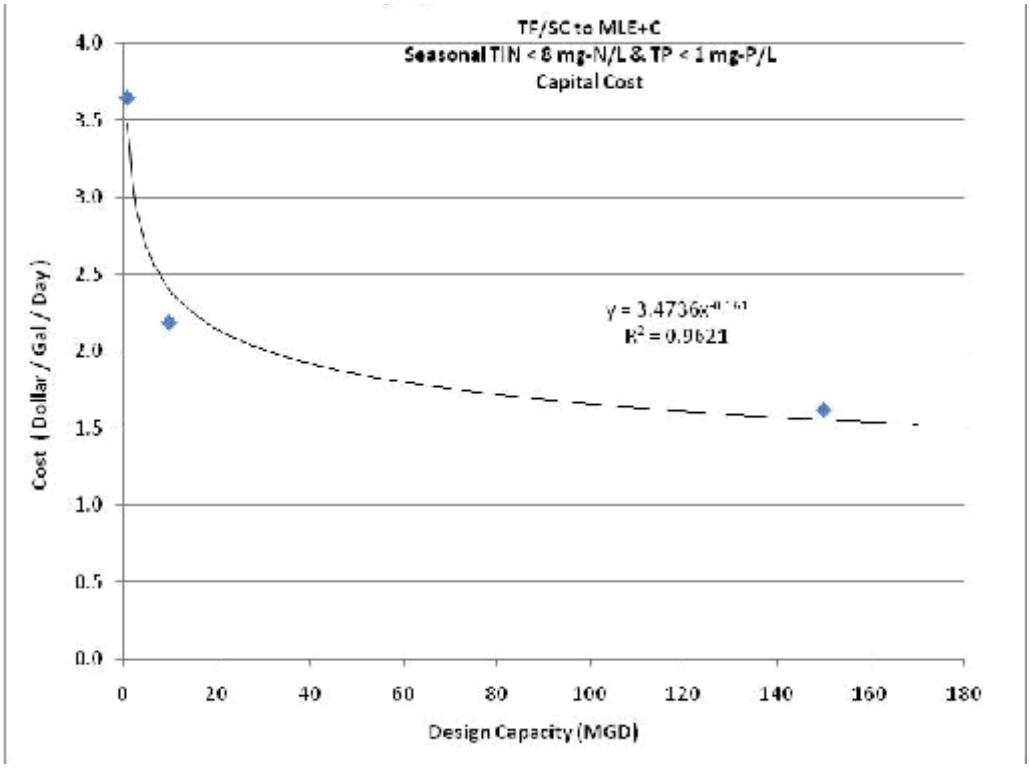


Figure 15-31. Capital Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective E Seasonally

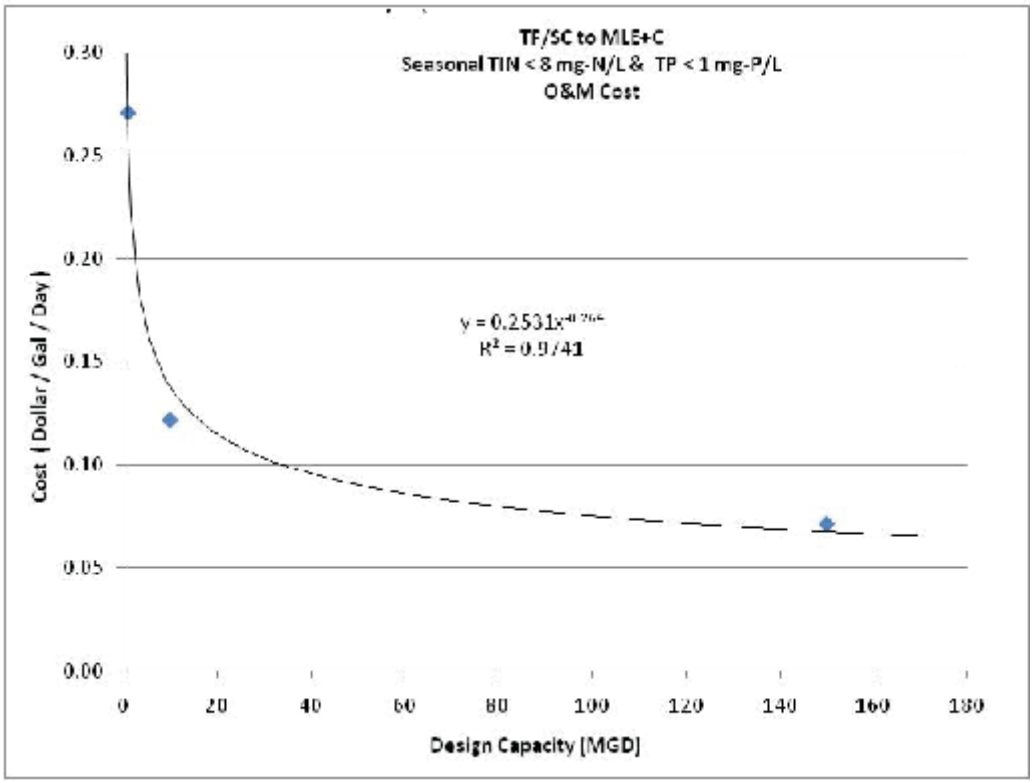


Figure 15-32. O&M Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective E Seasonal

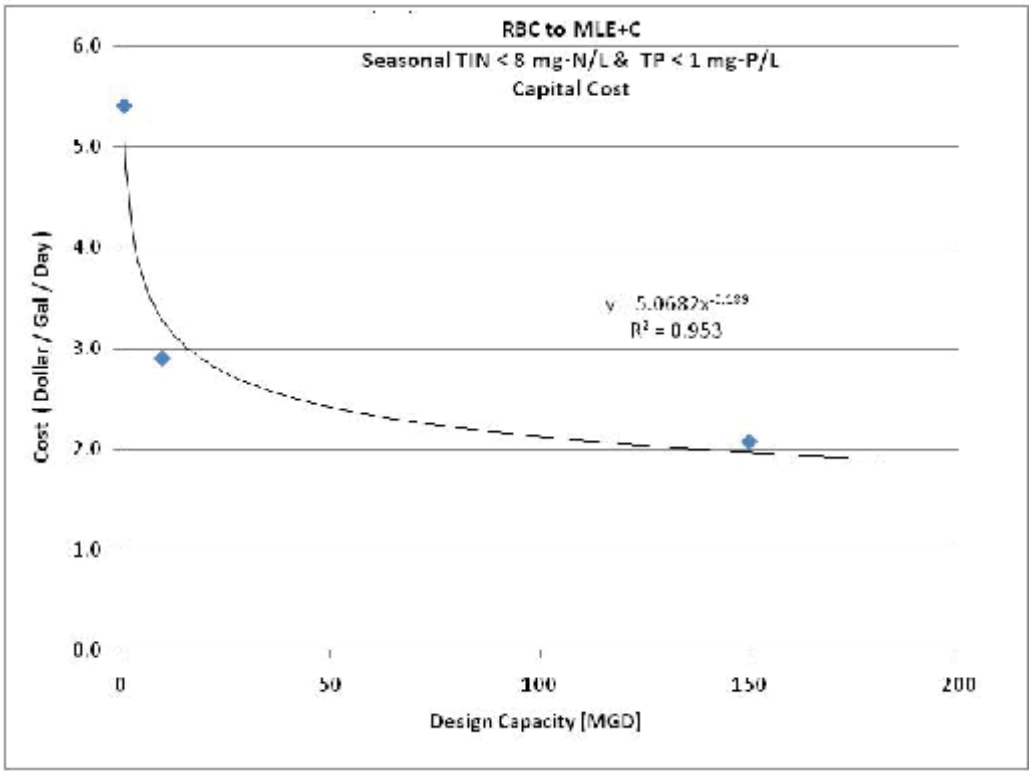


Figure 15-33. Capital Cost per Plant Capacity for RBC Plant Upgraded for Objective E Seasonally

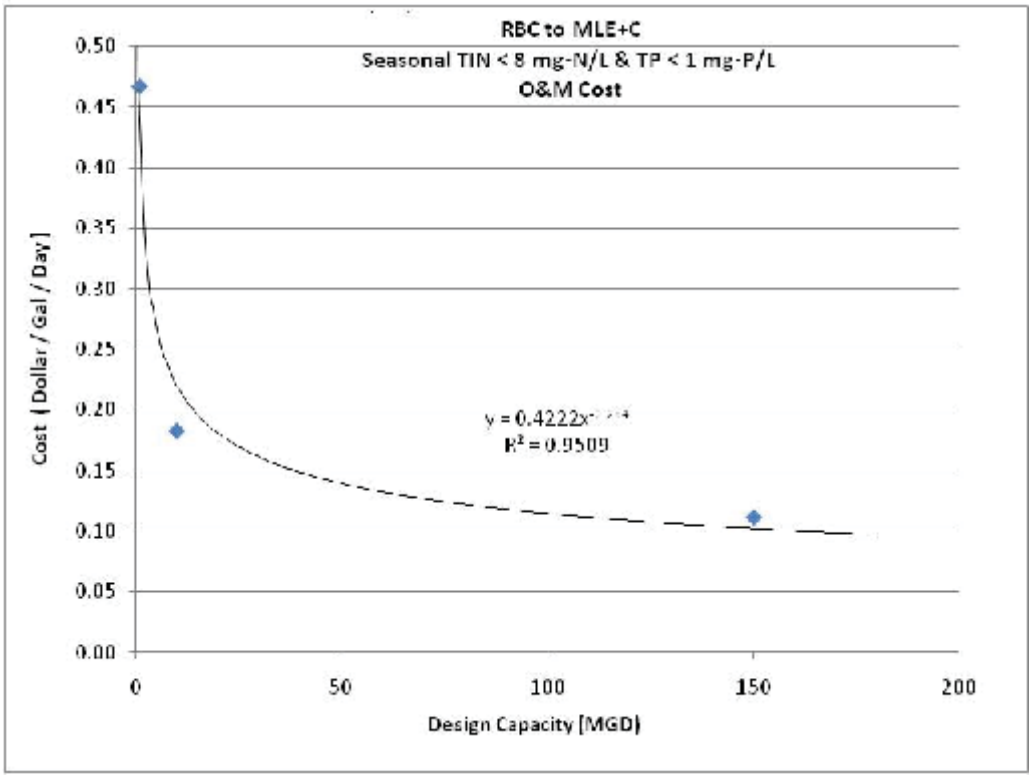


Figure 15-34. O&M Cost per Plant Capacity for RBC Plant Upgraded for Objective E Seasonal

TABLE 15-32.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TF PLANT TO ACHIEVE OBJECTIVE E SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$395,980	$2,114,252	$22,417,794
2014 Incremental O&M Cost	$453,794	$1,838,125	$16,835,248
Total Annual Cost	**$849,773**	**$3,952,377**	**$39,253,042**
Annual TIN Load Reduction (lb/yr)	19,418	194,180	2,912,700
Annual TP Load Reduction (lb/yr)	5,895	58,948	884,213
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$28.10	$13.39	$7.56
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$51.59	$22.93	$19.50
TIN Cost Equation:[a]	$y = 350.28x^{-0.261}$		
TIN Cost R-Square Value:	0.9854		
TP Cost Equation:[b]	$y = 236.13x^{-0.19}$		
TP Cost R-Square Value:	0.838		

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 15-33.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TF/SC PLANT TO ACHIEVE OBJECTIVE E SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$268,169	$1,607,188	$17,850,595
2014 Incremental O&M Cost	$304,715	$1,370,813	$12,075,471
Total Annual Cost	**$572,883**	**$2,978,001**	**$29,926,067**
Annual TIN Load Reduction (lb/yr)	19,418	194,180	2,912,700
Annual TP Load Reduction (lb/yr)	5,895	58,948	884,213
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$18.42	$8.27	$4.38
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$43.06	$23.26	$19.40
TIN Cost Equation:[a]	$y = 292.5x^{-0.285}$		
TIN Cost R-Square Value:	0.9873		
TP Cost Equation:[b]	$y = 153.11x^{-0.156}$		
TP Cost R-Square Value:	0.8815		

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 15-34.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE E SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$397,543	$2,131,692	$22,871,059
2014 Incremental O&M Cost	$525,494	$2,052,590	$18,750,301
Total Annual Cost	**$923,037**	**$4,184,282**	**$41,621,360**
Annual TIN Load Reduction (lb/yr)	19,418	194,180	2,912,700
Annual TP Load Reduction (lb/yr)	5,895	58,948	884,213
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$31.60	$14.62	$8.40
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$52.50	$22.83	$19.40
TIN Cost Equation:[a]	$y = 398.88x^{-0.263}$		
TIN Cost R-Square Value:	0.9803		
TP Cost Equation:[b]	$y = 225.71x^{-0.187}$		
TP Cost R-Square Value:	0.8407		

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

15.2.5 Membrane Biological Reactor Plants

Table 15-35 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective E seasonally for an MBR plant. Figures 15-35 and 15-36 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 15-36 presents the annualized unit costs for reducing nutrient loads.

TABLE 15-35.
ESTIMATED COST PER CAPACITY FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE E SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.19	$0.27	$0.07
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.15	$0.07	$0.04

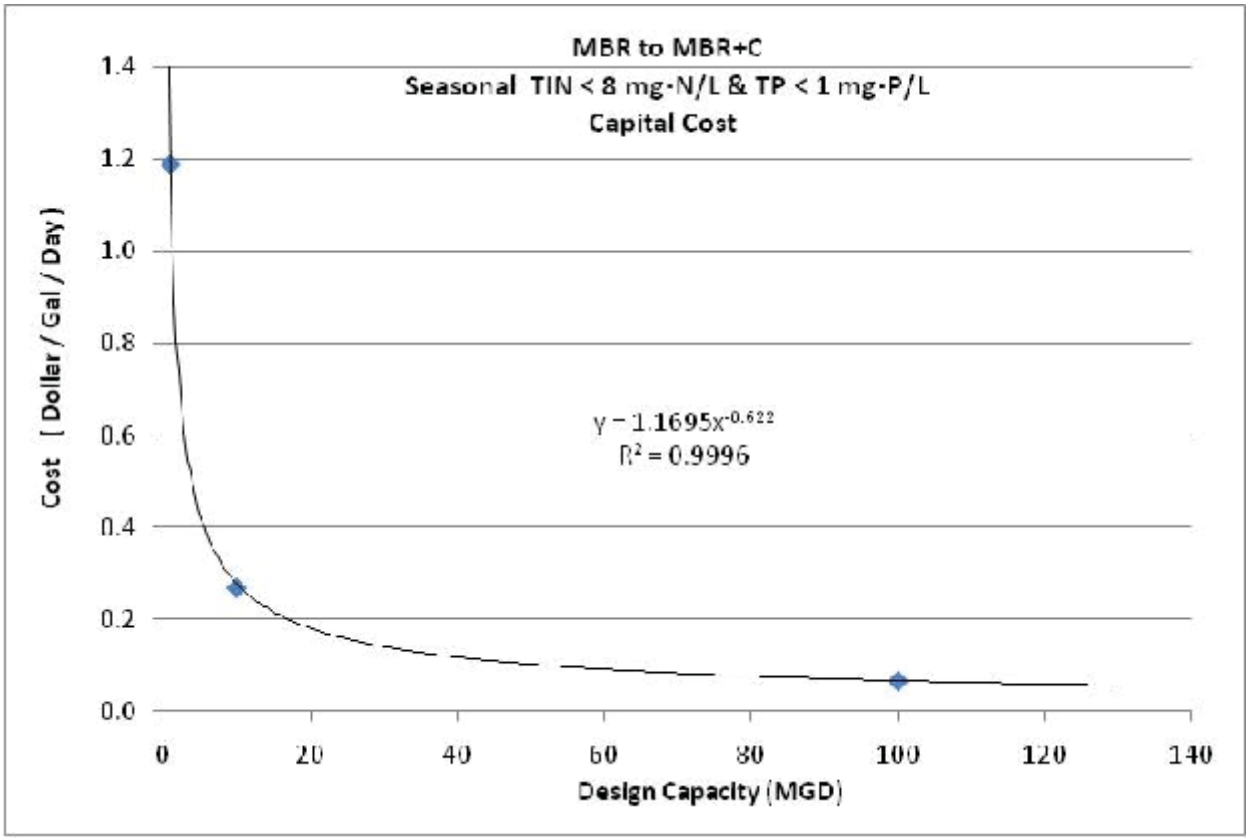


Figure 15-35. Capital Cost per Plant Capacity for MBR Plant Upgraded for Objective E Seasonally

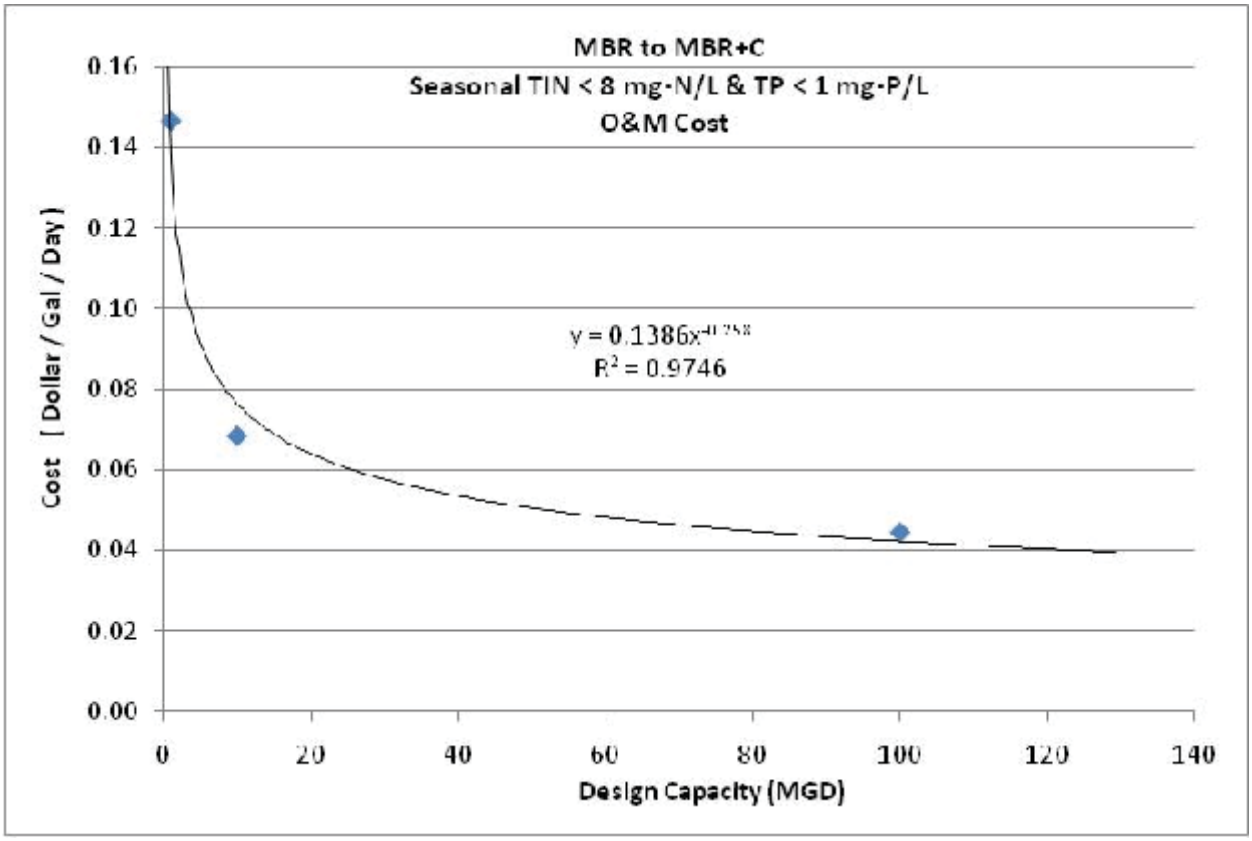


Figure 15-36. O&M Cost per Plant Capacity for MBR Plant Upgraded for Objective E Seasonal

TABLE 15-36.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE E SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	87,393	198,159	498,252
2014 Incremental O&M Cost	164,904	771,109	5,026,973
Total Annual Cost	**252,297**	**969,268**	**5,525,225**
Annual TIN Load Reduction (lb/yr)	0	0	0
Annual TP Load Reduction (lb/yr)	5,493	54,933	549,325
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	0	0	0
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$45.93	$17.64	$10.06
TIN Cost Equation and R-Square Value[a]			
TP Cost Equation:[b]	$y = 735.65x^{-0.33}$		
TP Cost R-Square Value:	0.9779		

a. Equation and R-square value for TIN not determined because annual cost estimates are below the level of precision that can be achieved using the CapdetWorks cost model.
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

15.2.6 High-Purity Oxygen Activated Sludge Plants

High-purity oxygen activated sludge plants were not evaluated for any objectives that include phosphorus removal, so no costs associated with Objective E were developed for these plants.

15.2.7 Aerated or Facultative Lagoon Plants

Table 15-37 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective E seasonally for an aerated lagoon plan. Figures 15-37 and 15-38 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 15-38 and Figures 15-39 and 15-40 summarize these costs for a facultative lagoon plant. Tables 15-39 and 15-40 present the annualized unit costs for reducing nutrient loads for aerated lagoon and facultative lagoon plants, respectively.

TABLE 15-37.
ESTIMATED COST PER CAPACITY FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE E SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$23.90	$17.39	$11.05	$7.32
Incremental Annual O&M Cost per gpd of Plant Capacity	$1.13	$0.67	$0.31	$0.15

TABLE 15-38.
ESTIMATED COST PER CAPACITY FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE E SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$23.76	$17.27	$10.96	$7.27
Incremental Annual O&M Cost per gpd of Plant Capacity	$1.40	$0.90	$0.47	$0.18

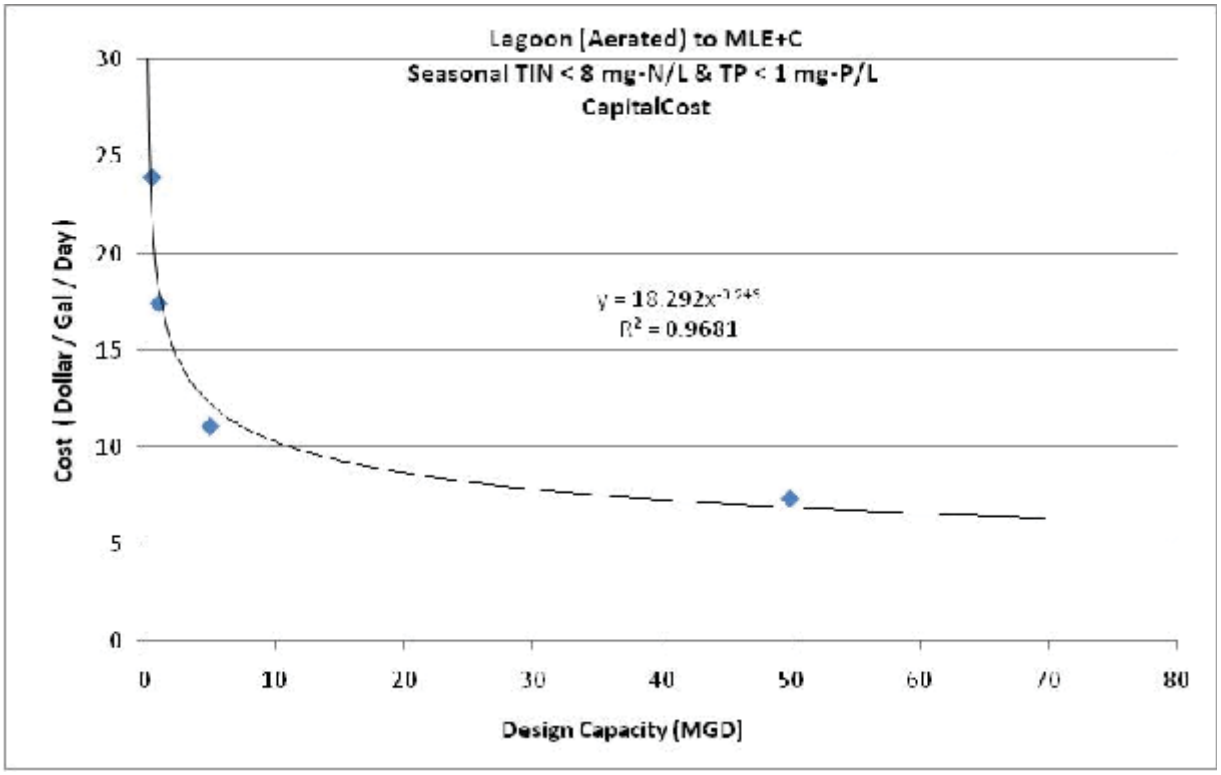


Figure 15-37. Capital Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective E Seasonally

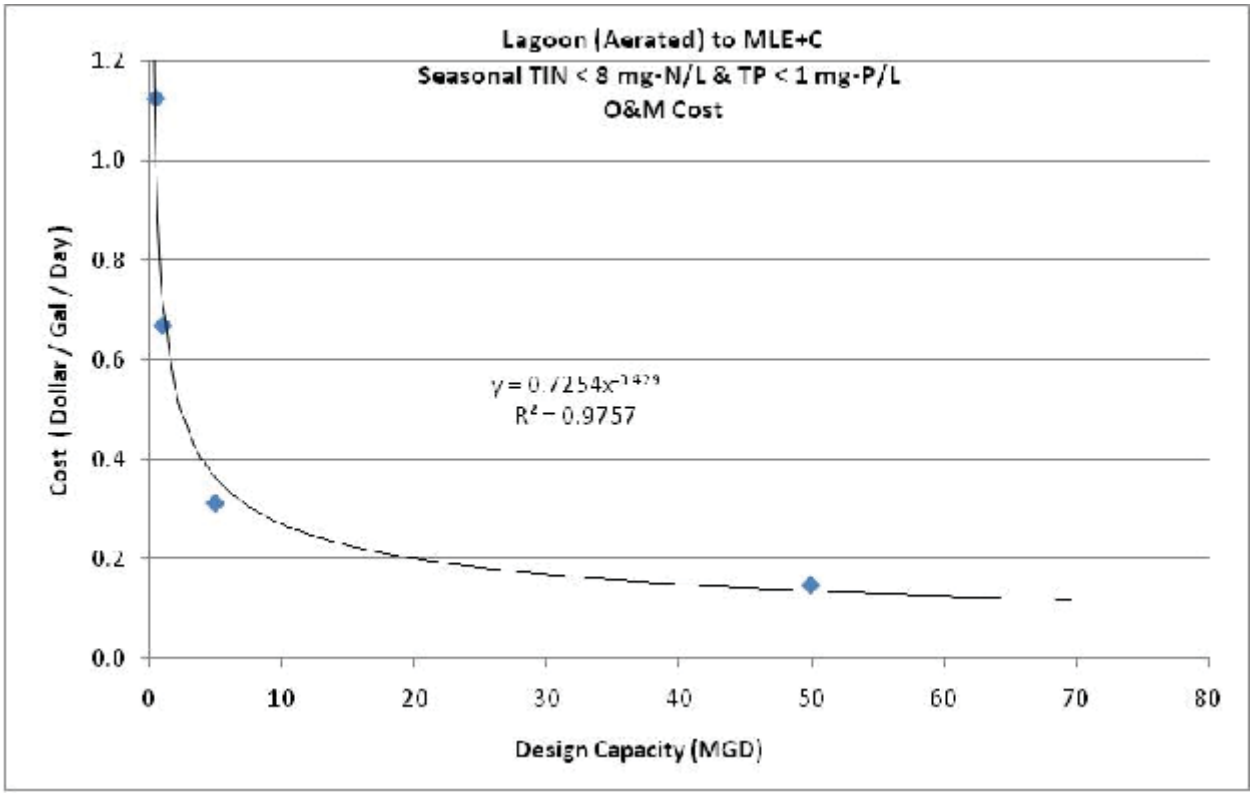


Figure 15-38. O&M Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective E Seasonal

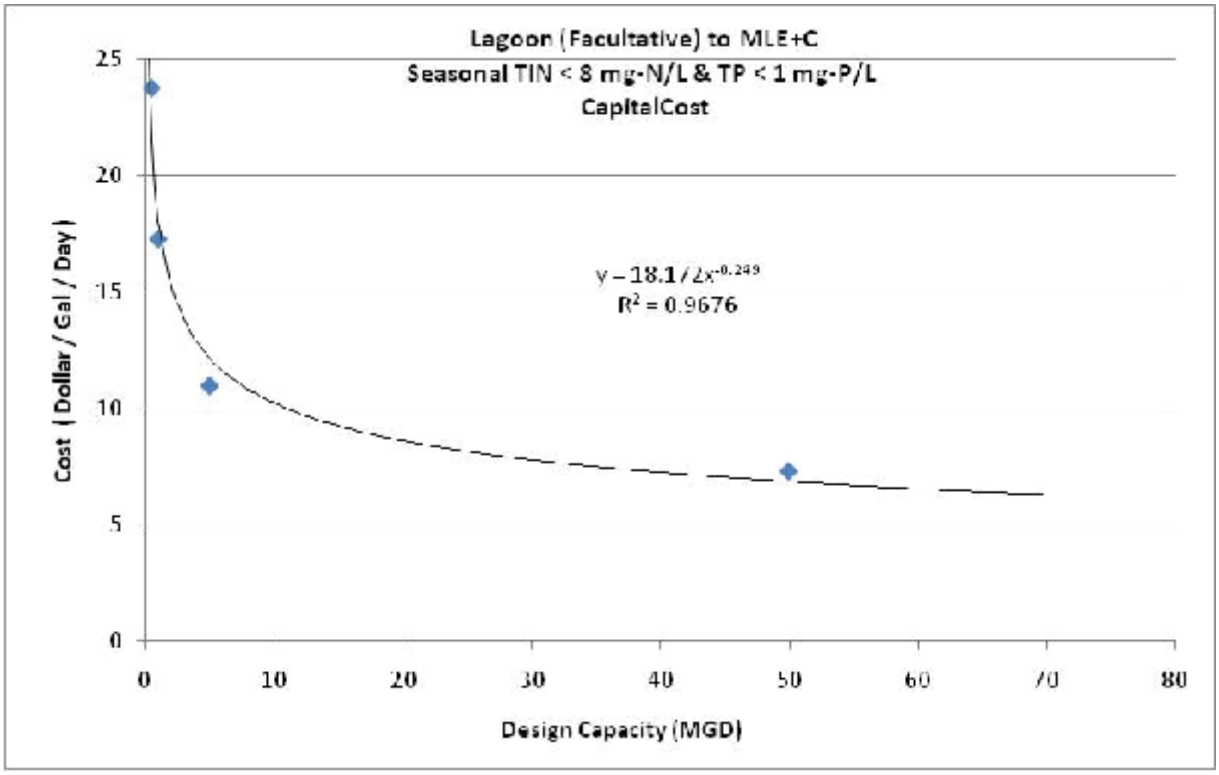


Figure 15-39. Capital Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective E Seasonally

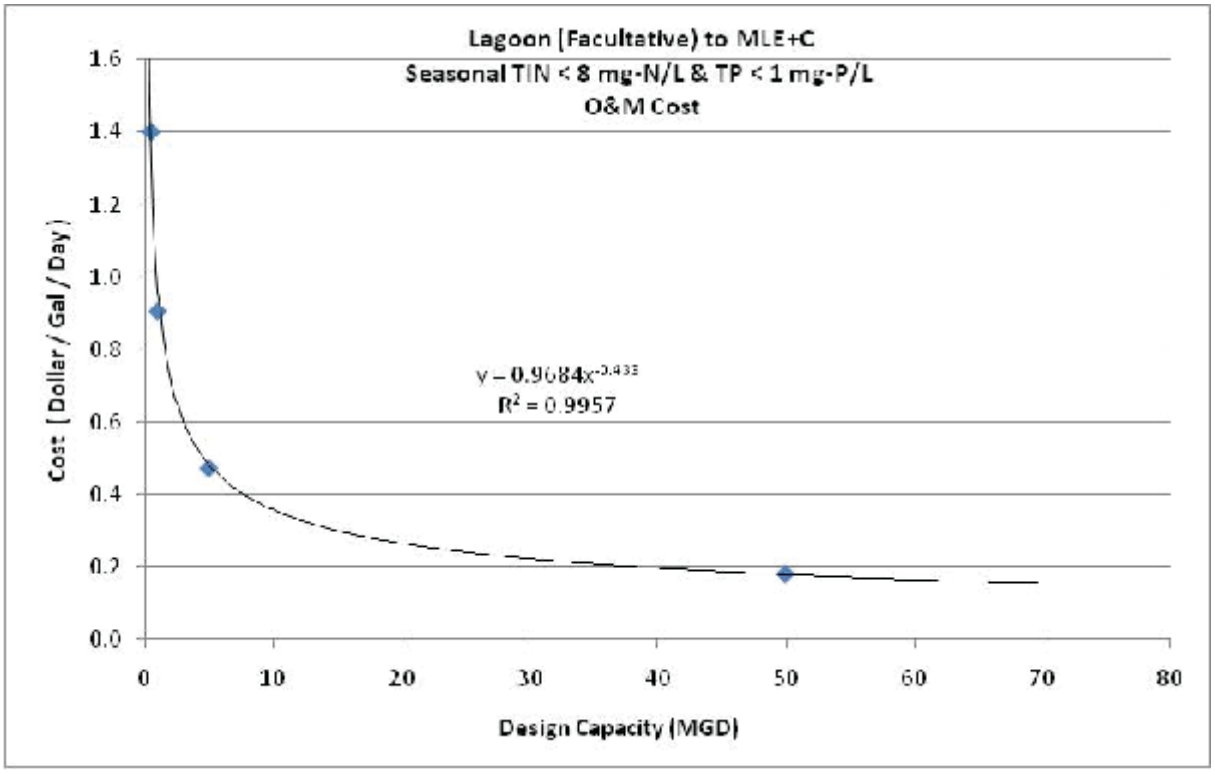


Figure 15-40. O&M Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective E Seasonal

TABLE 15-39.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE E SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$877,697	$1,277,193	$4,056,916	$26,881,497
2014 Incremental O&M Cost	$634,168	$754,125	$1,759,508	$8,327,583
Total Annual Cost	**$1,511,865**	**$2,031,318**	**$5,816,424**	**$35,209,080**
Annual TIN Load Reduction (lb/yr)	9,663	19,327	96,634	970,900
Annual TP Load Reduction (lb/yr)	2,947	5,895	29,474	294,738
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$118.93	$79.24	$47.44	$26.79
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$123.02	$84.80	$41.80	$32.21
TIN Cost Equation:[a]				$y = 1852.5x^{-0.311}$
TIN Cost R-Square Value:				0.976
TP Cost Equation:[b]				$y = 1053.4x^{-0.288}$
TP Cost R-Square Value:				0.9023

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 15-40.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE E SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$872,597	$1,268,720	$4,023,764	$26,707,101
2014 Incremental O&M Cost	$787,337	$1,017,803	$2,662,335	$10,214,853
Total Annual Cost	**$1,659,934**	**$2,286,523**	**$6,686,099**	**$36,921,954**
Annual TIN Load Reduction (lb/yr)	9,663	19,327	96,634	970,900
Annual TP Load Reduction (lb/yr)	2,947	5,895	29,474	294,738
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$135.89	$94.01	$57.90	$29.22
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$117.67	$79.66	$37.03	$29.01
TIN Cost Equation:[a]				$y = 2439.5x^{-0.323}$
TIN Cost R-Square Value:				0.9907
TP Cost Equation:[b]				$y = 1109.9x^{-0.301}$
TP Cost R-Square Value:				0.8912

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

CHAPTER 16.
COST EVALUATION, OBJECTIVE F

16.1 YEAR-ROUND NUTRIENT REMOVAL

167.1.1 Extended Aeration Plants

Table 16-1 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective F year-round for an extended aeration plant using mechanical aeration. Figures 16-1 and 16-2 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 16-2 and Figures 16-3 a nd 16-4 summarize these costs for an extended aeration plant using diffuser aeration. Tables 16-3 and 16-4 present the annualized unit costs for reducing nutrient loads for mechanical aeration and diffuser aeration plants, respectively.

TABLE 16-1.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE F YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$8.44	$3.92	$3.25
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.61	$0.26	$0.18

TABLE 16-2.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE F YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$4.72	$2.42	$1.36
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.42	$0.20	$0.15

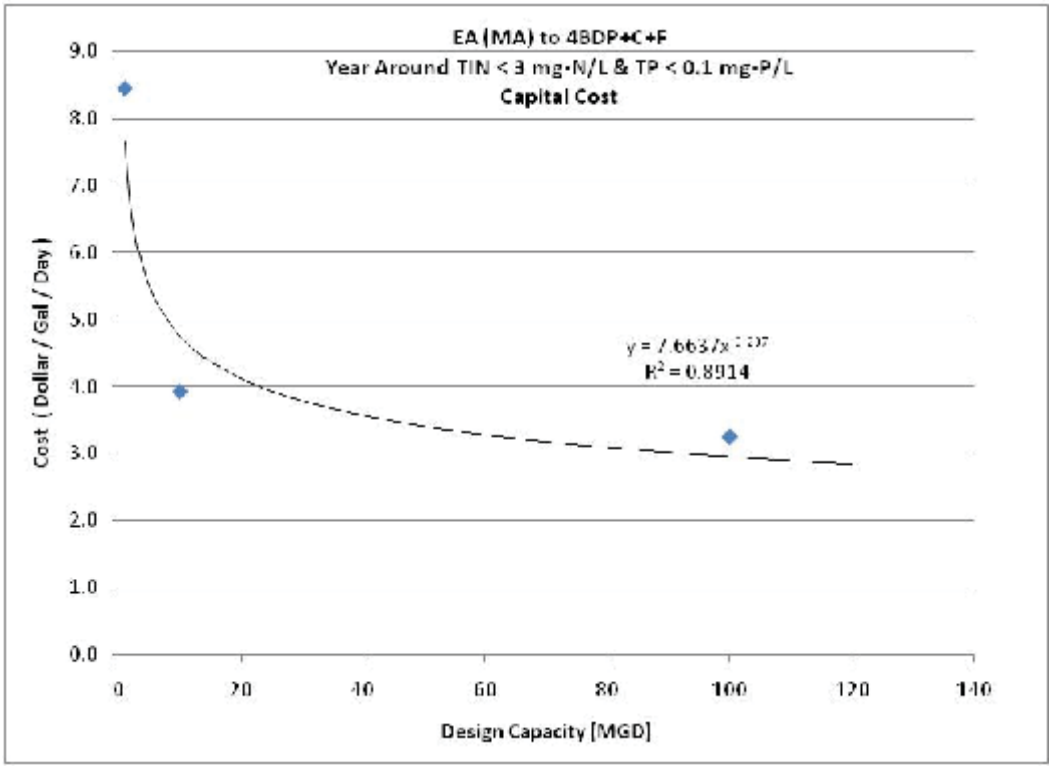


Figure 16-1. Capital Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective F Year-Round

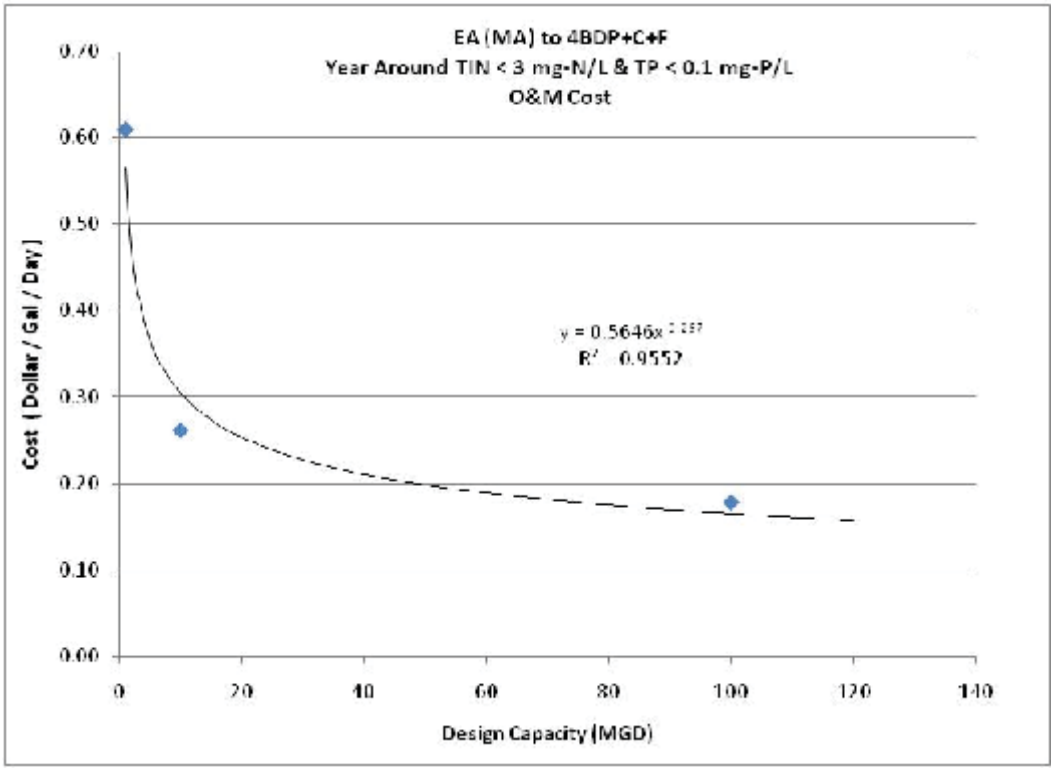


Figure 16-2. O&M Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective F Year-Round

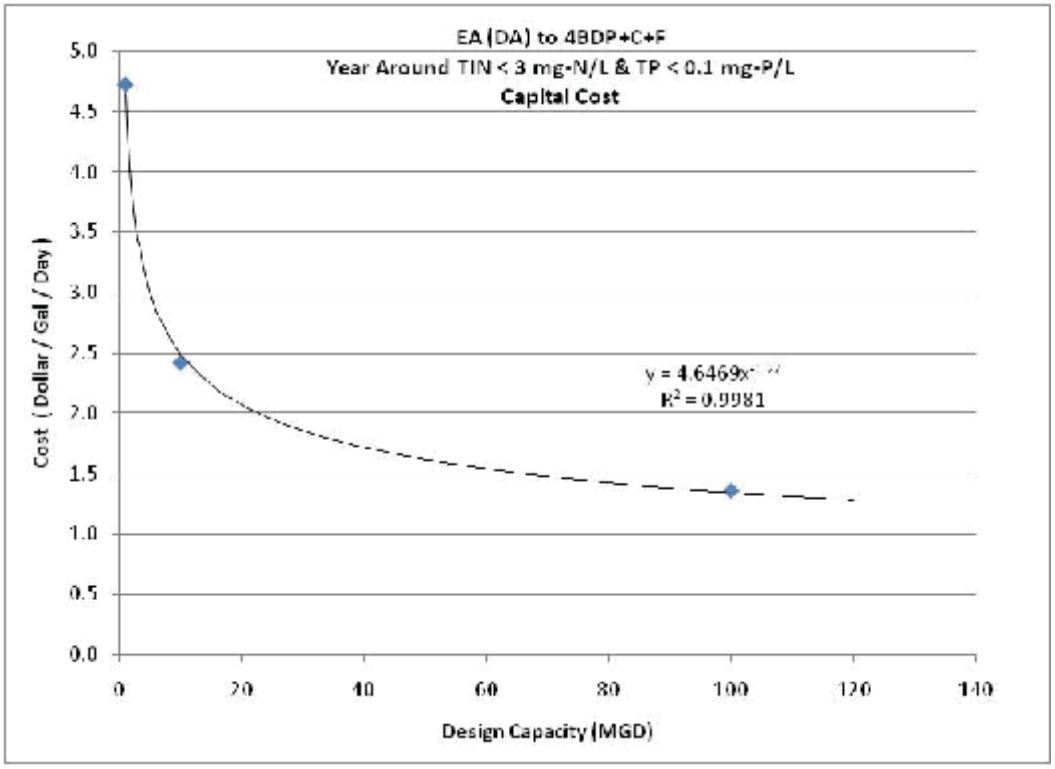


Figure 16-3. Capital Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective F Year-Round

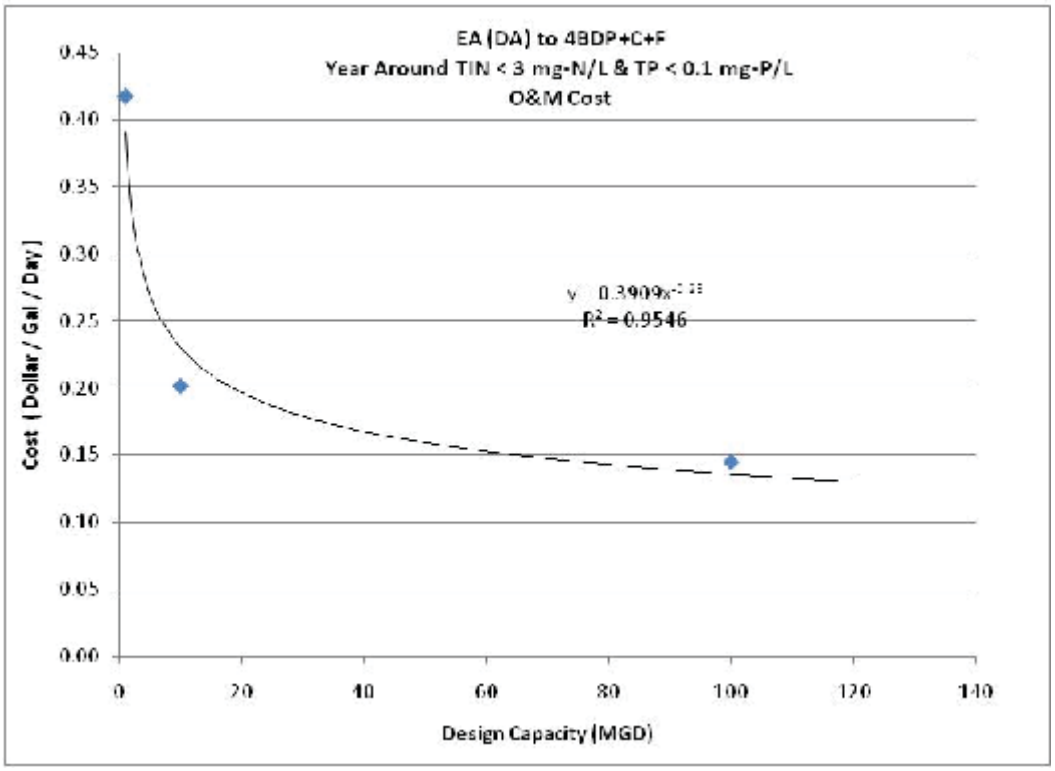


Figure 16-4. O&M Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective F Year-Round

TABLE 16-3.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EXTENDED AERATION (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE F YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$519,755	$2,879,976	$23,842,223
2014 Incremental O&M Cost	$686,335	$2,942,508	$20,025,334
Total Annual Cost	**$1,306,090**	**$5,822,483**	**$43,867,557**
Annual TIN Load Reduction (lb/yr)	45,406	454,060	4,540,600
Annual TP Load Reduction (lb/yr)	12,775	127,750	1,277,500
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$16.61	$5.27	$3.34
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$43.20	$26.86	$22.46
TIN Cost Equation:[a]	$y = 620.03x^{-0.348}$		
TIN Cost R-Square Value:	0.9416		
TP Cost Equation:[b]	$y = 157.5x^{-0.142}$		
TP Cost R-Square Value:	0.936		

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 16-4.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EXTENDED AERATION (DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE F YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$346,644	$1,777,662	$10,005,716
2014 Incremental O&M Cost	$470,294	$2,269,116	$16,326,349
Total Annual Cost	**$816,938**	**$4,046,778**	**$26,332,066**
Annual TIN Load Reduction (lb/yr)	45,370	453,695	4,536,950
Annual TP Load Reduction (lb/yr)	12,739	127,385	1,273,850
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$6.53	$1.90	$0.32
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$40.89	$24.99	$19.52
TIN Cost Equation:[a]	$y = 8019.1x^{-0.655}$		
TIN Cost R-Square Value:	0.9892		
TP Cost Equation:[b]	$y = 179.07x^{-0.161}$		
TP Cost R-Square Value:	0.9646		

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

16.1.2 Conventional Activated Sludge Plants

Table 16-5 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective F year-round for a conventional activated sludge plant. Figures 16-5 and 16-6 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 16-6 presents the annualized unit costs for reducing nutrient loads.

TABLE 16-5.
ESTIMATED COST PER CAPACITY FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE F YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$11.00	$6.45	$4.16
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.59	$0.33	$0.24

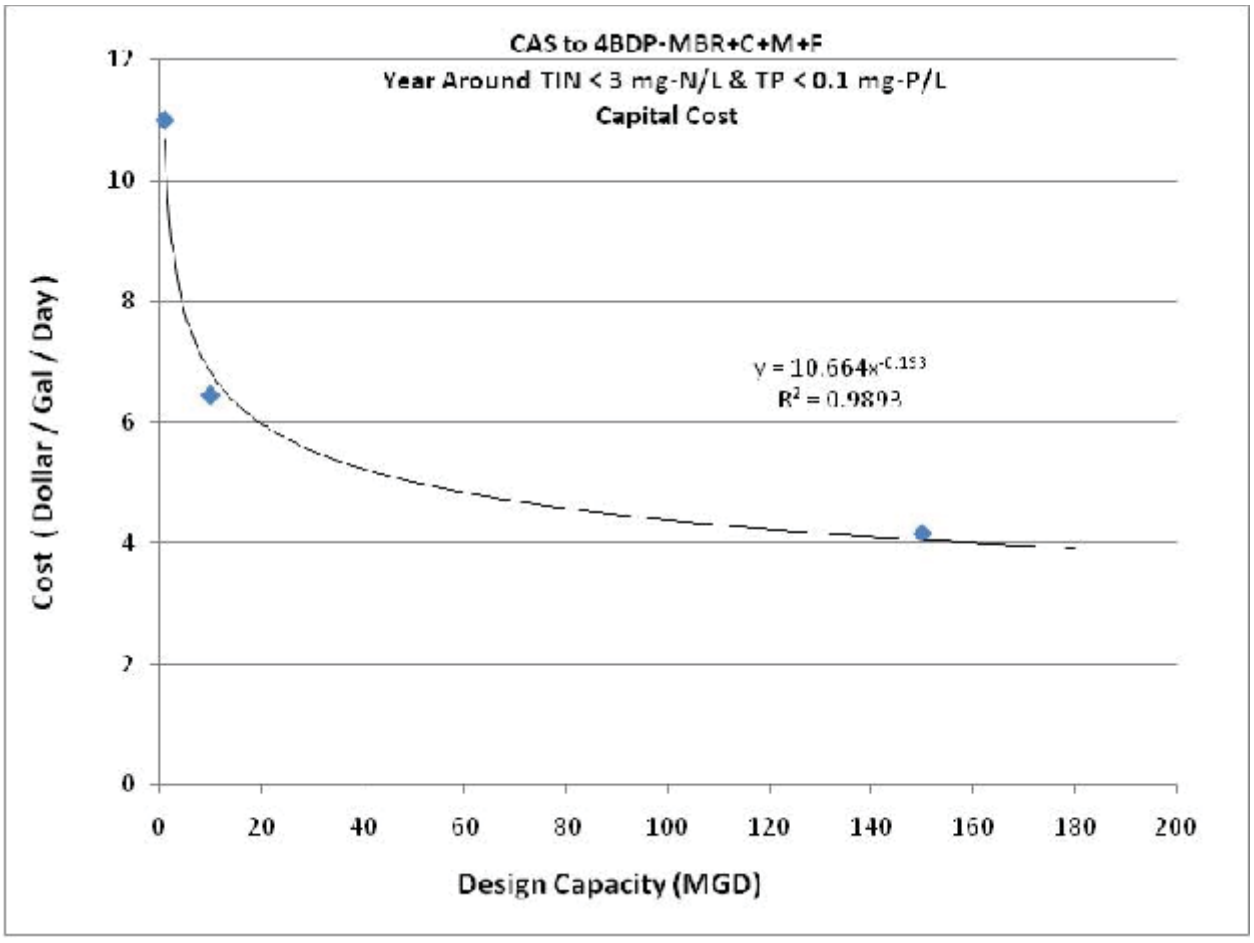


Figure 16-5. Capital Cost per Plant Capacity for CAS Plant Upgraded for Objective F Year-Round

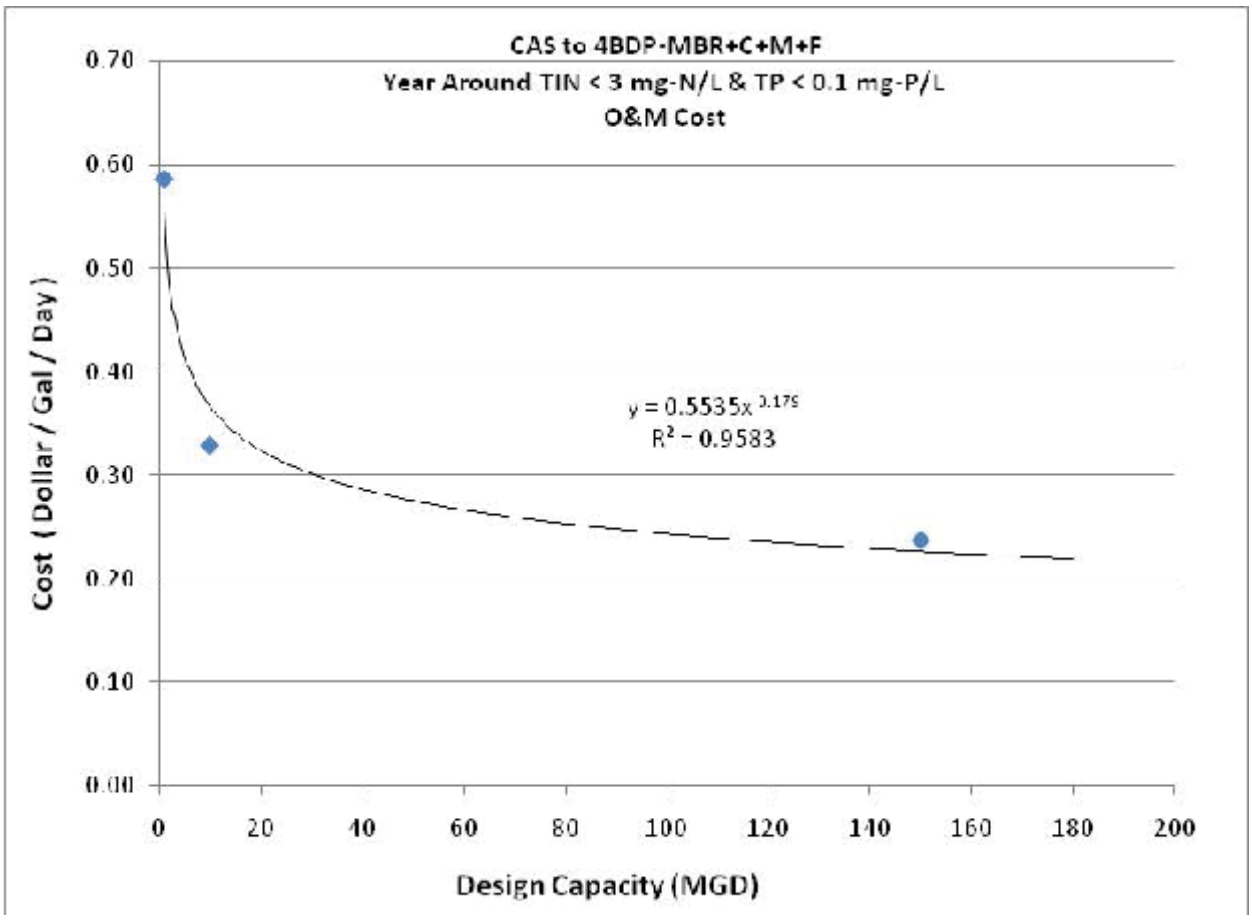


Figure 16-6. O&M Cost per Plant Capacity for CAS Plant Upgraded for Objective F Year-Round

TABLE 16-6.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE F YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$808,295	$4,735,944	$45,832,152
2014 Incremental O&M Cost	$660,329	$3,707,577	$40,125,423
Total Annual Cost	**$1,468,624**	**$8,443,521**	**$85,957,575**
Annual TIN Load Reduction (lb/yr)	45,479	454,790	6,821,850
Annual TP Load Reduction (lb/yr)	13,140	131,400	1,971,000
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$19.53	$11.88	$7.38
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$44.17	$23.14	$18.08
TIN Cost Equation:[a]			$y = 153.13x^{-0.194}$
TIN Cost R-Square Value:			0.9965
TP Cost Equation:[b]			$y = 214.81x^{-0.176}$
TP Cost R-Square Value:			0.9129

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

16.1.3 Sequencing Batch Reactor Plants

Table 16-7 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective F year-round for an SBR plant. Figures 16-7 and 16-8 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 16-8 presents the annualized unit costs for reducing nutrient loads.

TABLE 16-7.
ESTIMATED COST PER CAPACITY FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE F YEAR-ROUND

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Capital Cost per gpd of Plant Capacity	$4.85	$2.97	$1.80
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.86	$0.39	$0.19

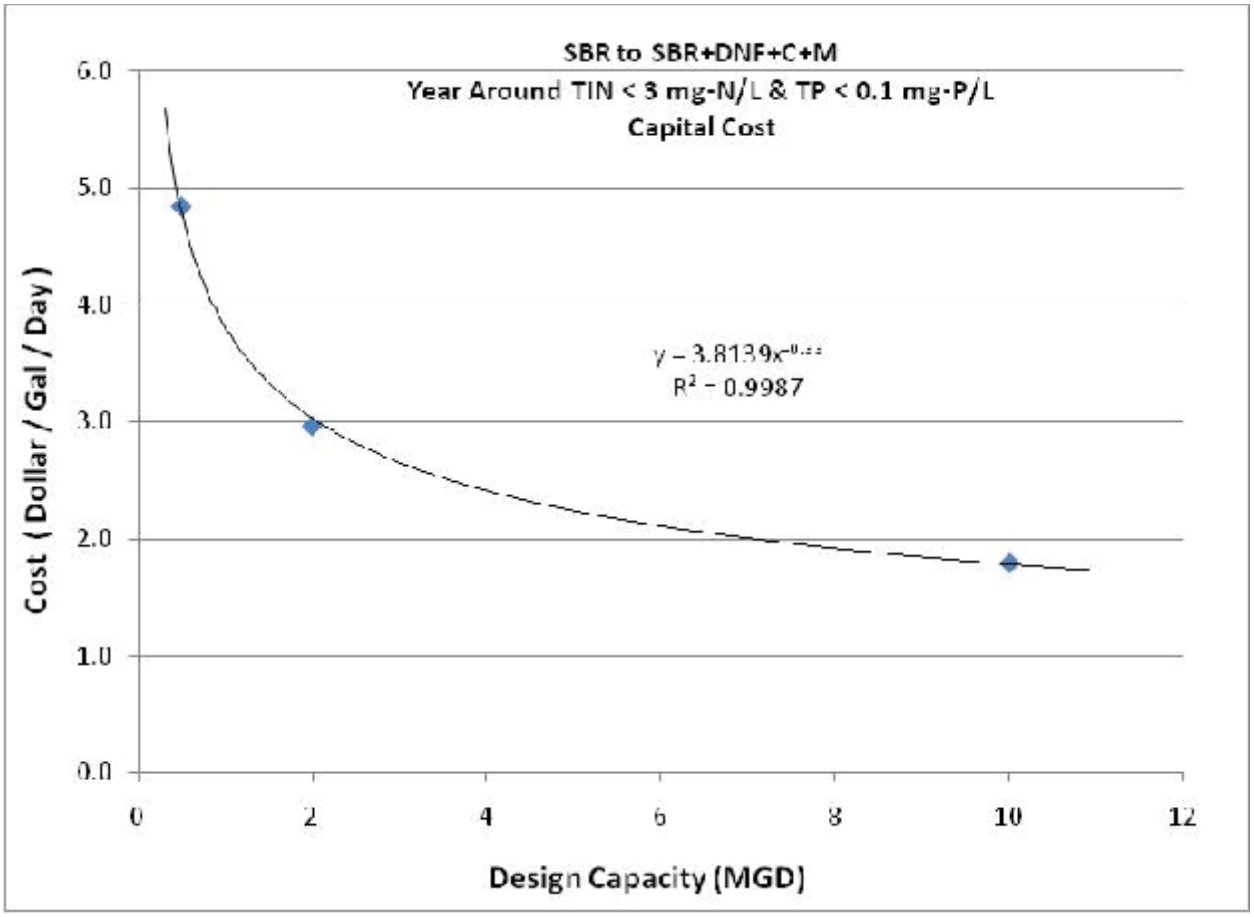


Figure 16-7. Capital Cost per Plant Capacity for SBR Plant Upgraded for Objective F Year-Round

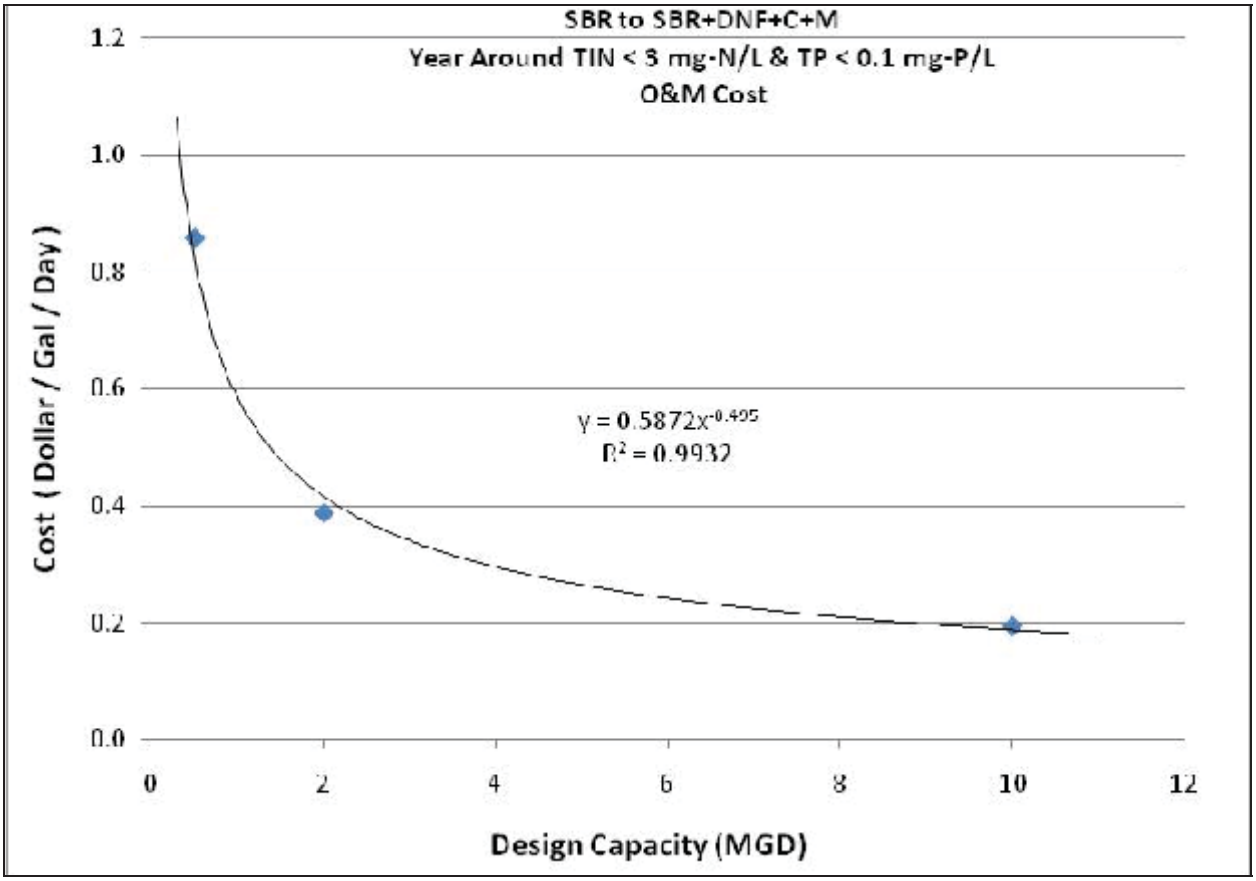


Figure 16-8. O&M Cost per Plant Capacity for SBR Plant Upgraded for Objective F Year-Round

TABLE 16-8.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE F YEAR-ROUND

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Annualized Capital Cost	$178,058	$436,508	$1,322,023
2014 Incremental O&M Cost	$483,732	$873,775	$2,184,463
Total Annual Cost	**$661,790**	**$1,310,283**	**$3,506,487**
Annual TIN Load Reduction (lb/yr)	2,537	10,147	50,735
Annual TP Load Reduction (lb/yr)	2,957	11,826	59,130
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$172.21	$71.54	$29.76
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$76.08	$49.41	$33.77
TIN Cost Equation:[a]			$y = 16486x^{-0.585}$
TIN Cost R-Square Value:			0.9981
TP Cost Equation:[b]			$y = 646.37x^{-0.27}$
TP Cost R-Square Value:			0.9937

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

16.1.4 Trickling Filter, Trickling Filter/Solids Contact and Rotating Biological Contactor Plants

Table 16-9 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective F year-round for a trickling filter plant. Figures 16-9 and 16-10 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 16-10 and Figures 16-1 and 16-12 summarize these costs for a trickling filter/solids contact plant. Table 16-11 and Figures 16-13 and 16-14 summarize these costs for an RBC plant. Tables 16-12, 16-13 and 16-14 present the annualized unit costs for reducing nutrient loads for TF, TF/SC and RBC plants, respectively.

TABLE 16-9.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER PLANT TO ACHIEVE OBJECTIVE F YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$12.44	$7.62	$4.53
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.65	$0.36	$0.24

TABLE 16-10.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER/SOLIDS CONTACT PLANT TO ACHIEVE OBJECTIVE F YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$11.17	$7.06	$4.21
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.52	$0.31	$0.21

TABLE 16-11.
ESTIMATED COST PER CAPACITY FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE F YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$12.44	$7.64	$4.58
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.71	$0.37	$0.25

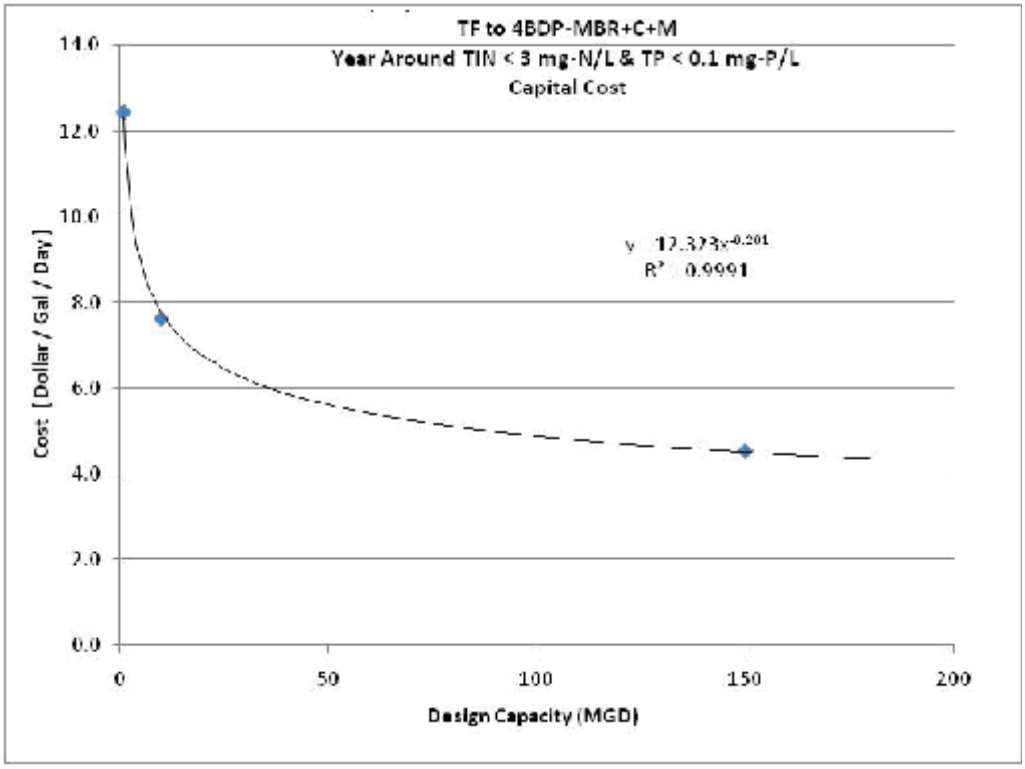


Figure 16-9. Capital Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective F Year-Round

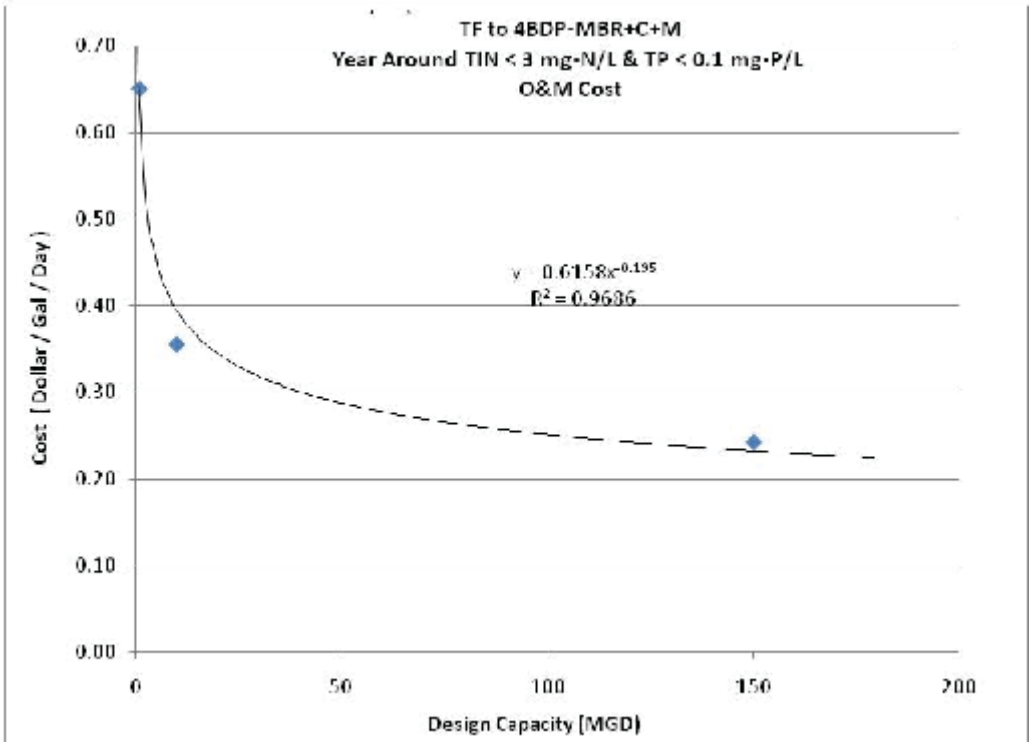


Figure 16-10. O&M Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective F Year-Round

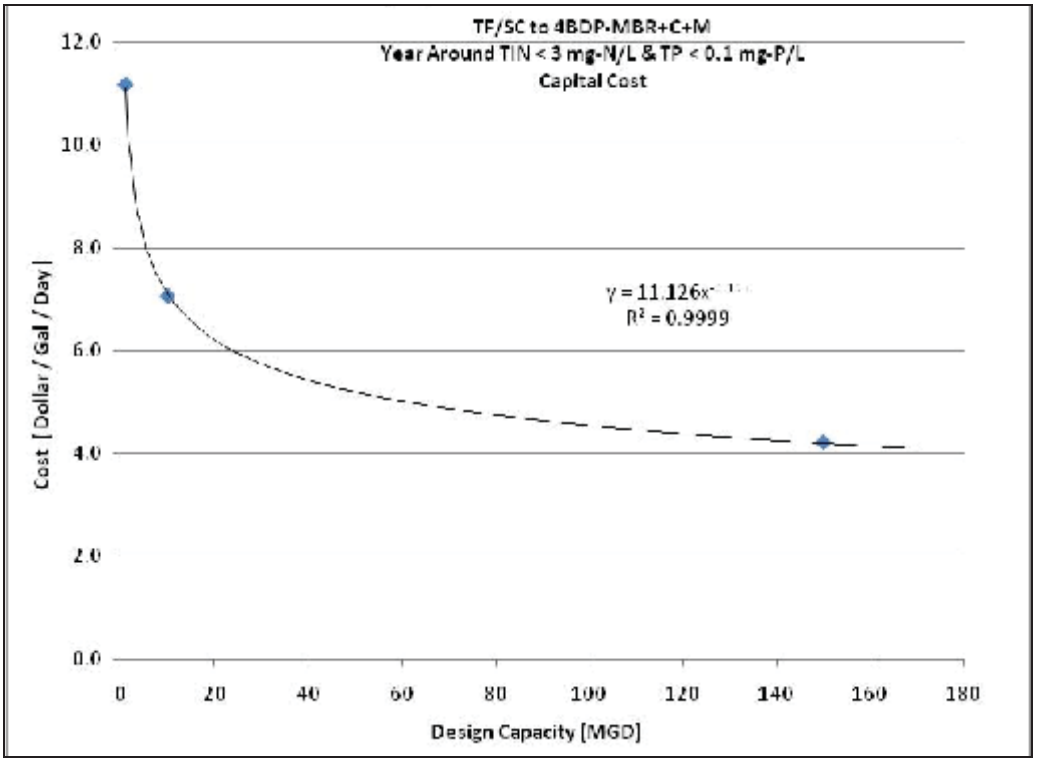


Figure 16-11. Capital Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective F Year-Round

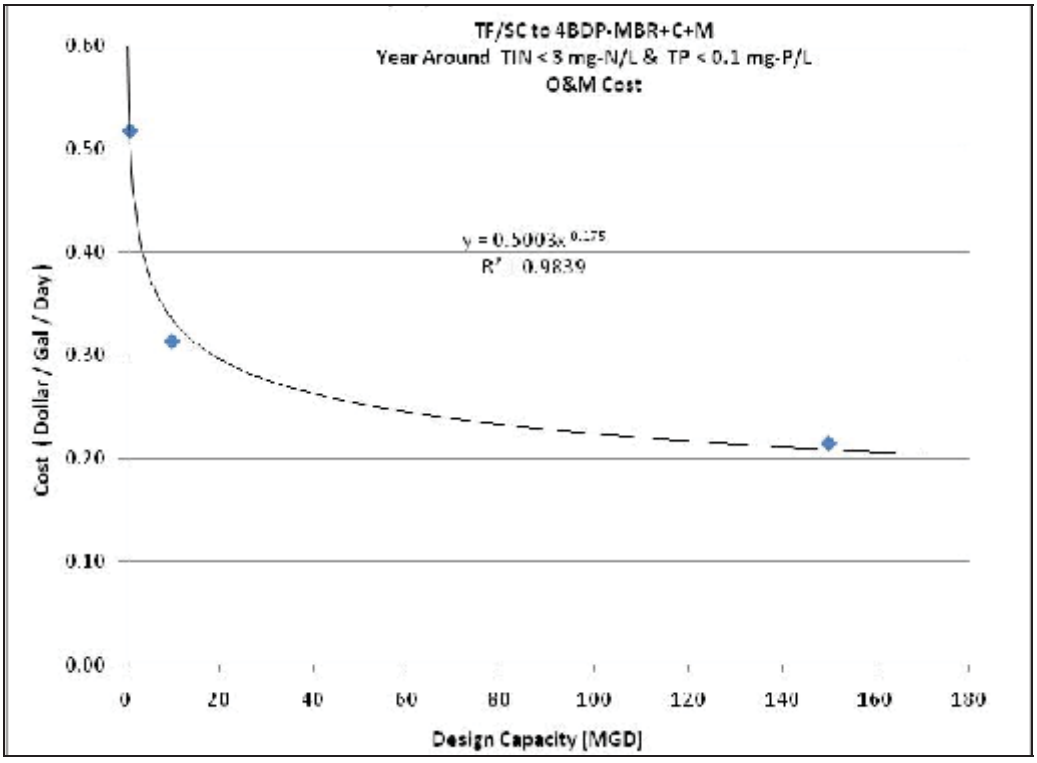


Figure 16-12. O&M Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective F Year-Round

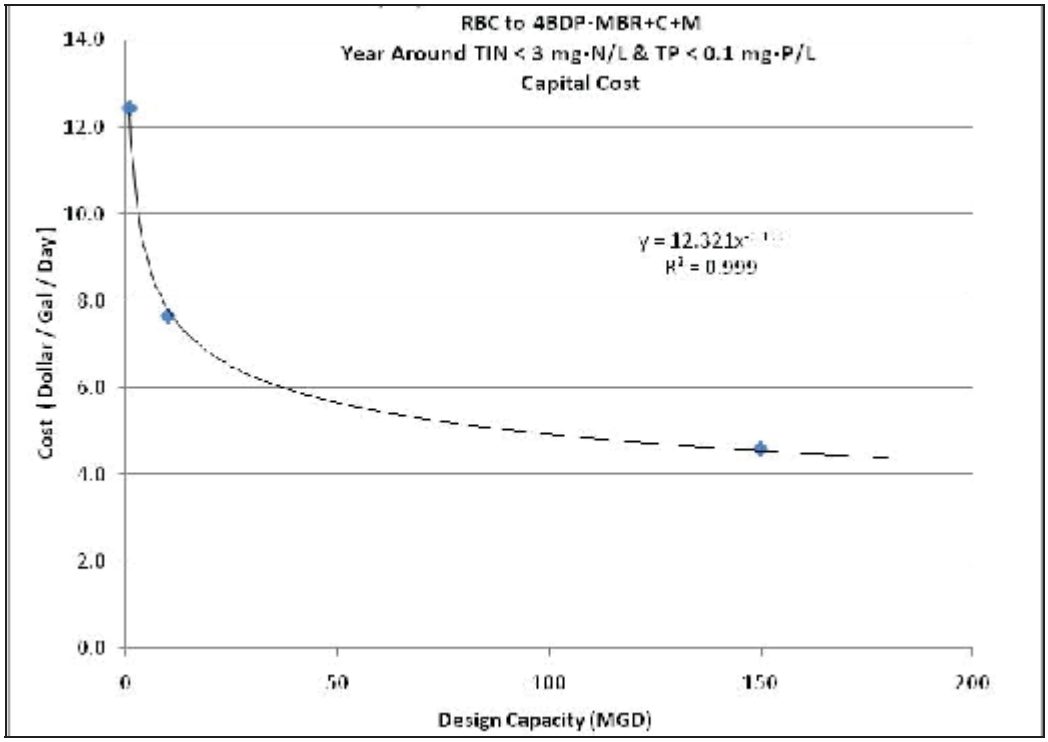


Figure 16-13. Capital Cost per Plant Capacity for RBC Upgraded for Objective F Year-Round

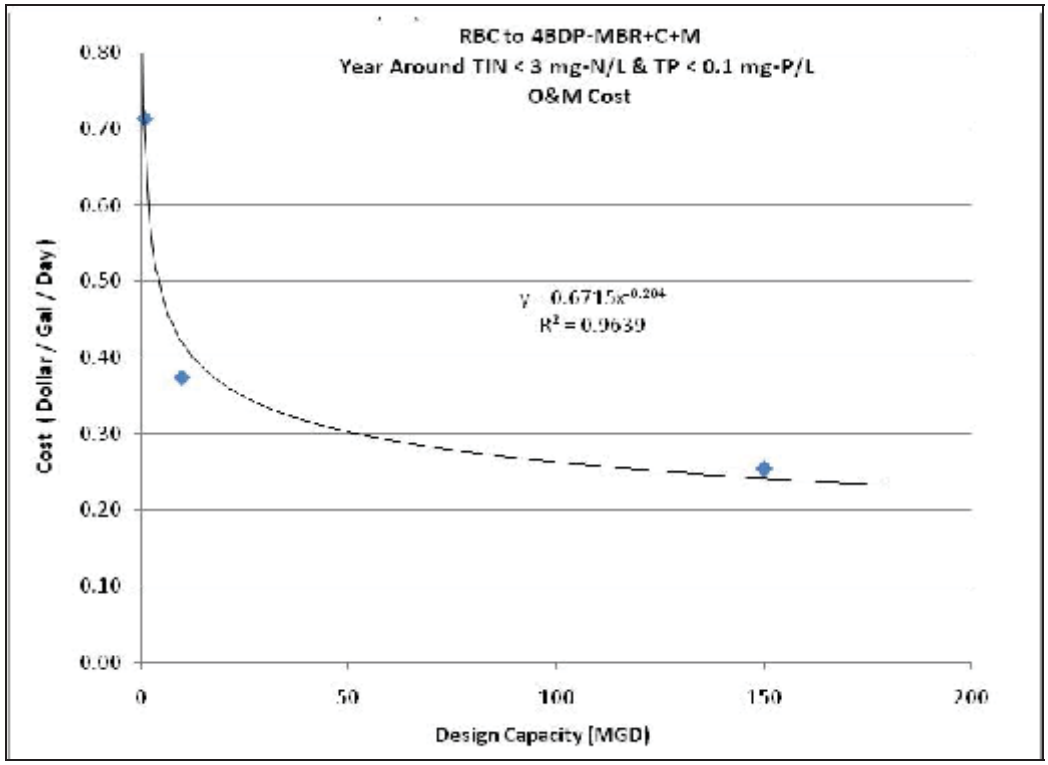


Figure 16-14. O&M Cost per Plant Capacity for RBC Plant Upgraded for Objective F Year-Round

TABLE 16-12.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TRICKLING FILTER PLANT TO ACHIEVE OBJECTIVE F YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$913,676	$5,594,150	$49,901,730
2014 Incremental O&M Cost	$732,176	$3,998,971	$41,046,652
Total Annual Cost	**$1,645,852**	**$9,593,121**	**$90,948,382**
Annual TIN Load Reduction (lb/yr)	45,479	454,790	6,821,850
Annual TP Load Reduction (lb/yr)	13,140	131,400	1,971,000
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$23.82	$14.70	$8.34
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$42.81	$22.13	$17.27
TIN Cost Equation:[a]			$y = 225.12x^{-0.209}$
TIN Cost R-Square Value:			1
TP Cost Equation:[b]			$y = 213.36x^{-0.179}$
TP Cost R-Square Value:			0.911

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 16-13.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TRICKLING FILTER/SOLIDS CONTACT PLANT TO ACHIEVE OBJECTIVE F YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$820,226	$5,185,883	$46,395,714
2014 Incremental O&M Cost	$583,097	$3,531,660	$36,286,875
Total Annual Cost	**$1,403,323**	**$8,717,542**	**$82,682,589**
Annual TIN Load Reduction (lb/yr)	45,479	454,790	6,821,850
Annual TP Load Reduction (lb/yr)	13,140	131,400	1,971,000
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$18.42	$12.72	$7.15
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$43.06	$22.33	$17.22
TIN Cost Equation:[a]			$y = 143.98x^{-0.19}$
TIN Cost R-Square Value:			0.9939
TP Cost Equation:[b]			$y = 218.9x^{-0.18}$
TP Cost R-Square Value:			0.9173

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 16-14.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE F YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$914,005	$5,614,551	$50,425,740
2014 Incremental O&M Cost	$803,877	$4,213,437	$42,961,705
Total Annual Cost	**$1,717,881**	**$9,827,988**	**$93,387,446**
Annual TIN Load Reduction (lb/yr)	45,479	454,790	6,821,850
Annual TP Load Reduction (lb/yr)	13,140	131,400	1,971,000
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$25.33	$15.19	$8.71
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$43.07	$22.24	$17.24
TIN Cost Equation:[a]	$y = 246.43x^{-0.213}$		
TIN Cost R-Square Value:	0.9995		
TP Cost Equation:[b]	$y = 218.09x^{-0.18}$		
TP Cost R-Square Value:	0.9141		

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

16.1.5 Membrane Biological Reactor Plants

Table 16-15 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective F year-round for an MBR plant. Figures 16-15 and 16-16 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 16-16 presents the annualized unit costs for reducing nutrient loads.

TABLE 16-15.
ESTIMATED COST PER CAPACITY FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE F YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.35	$0.35	$0.28
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.20	$0.12	$0.10

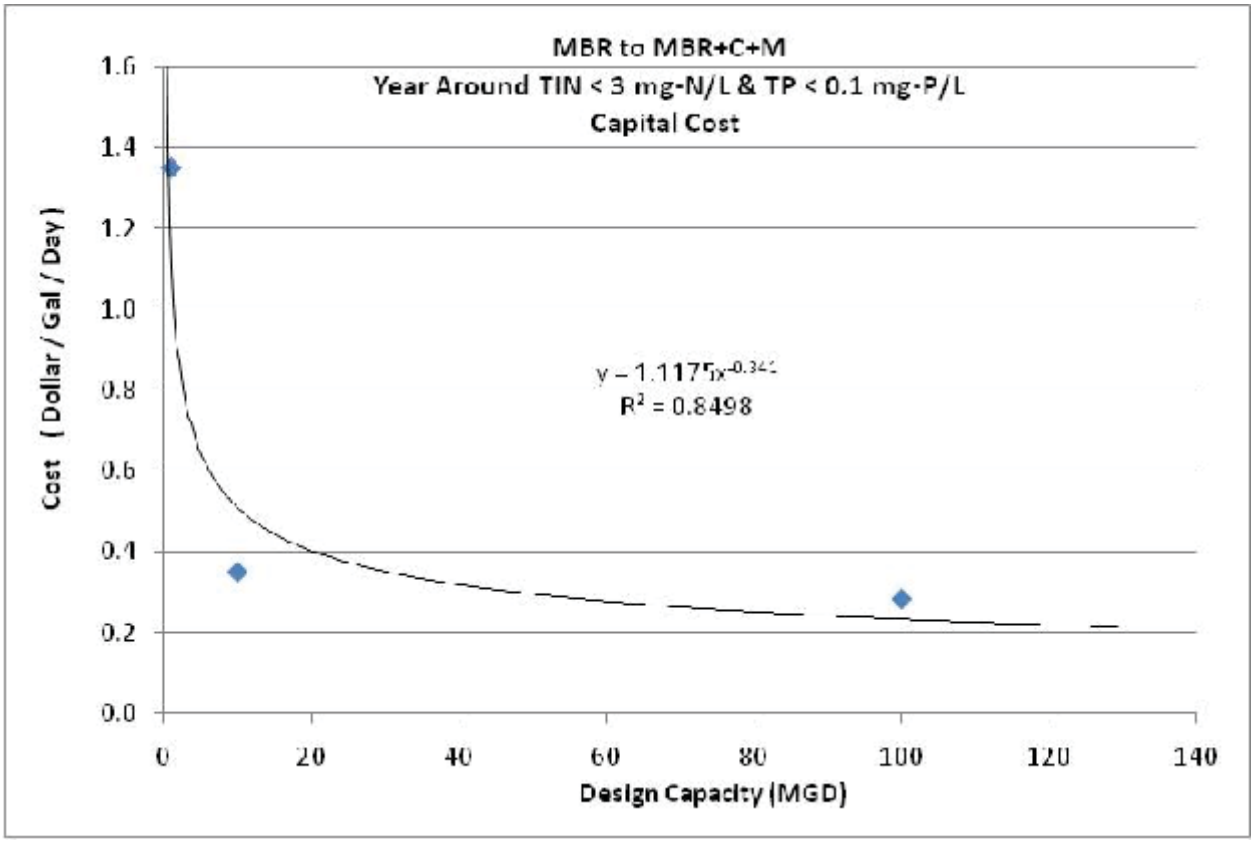


Figure 16-15. Capital Cost per Plant Capacity for MBR Plant Upgraded for Objective F Year-Round

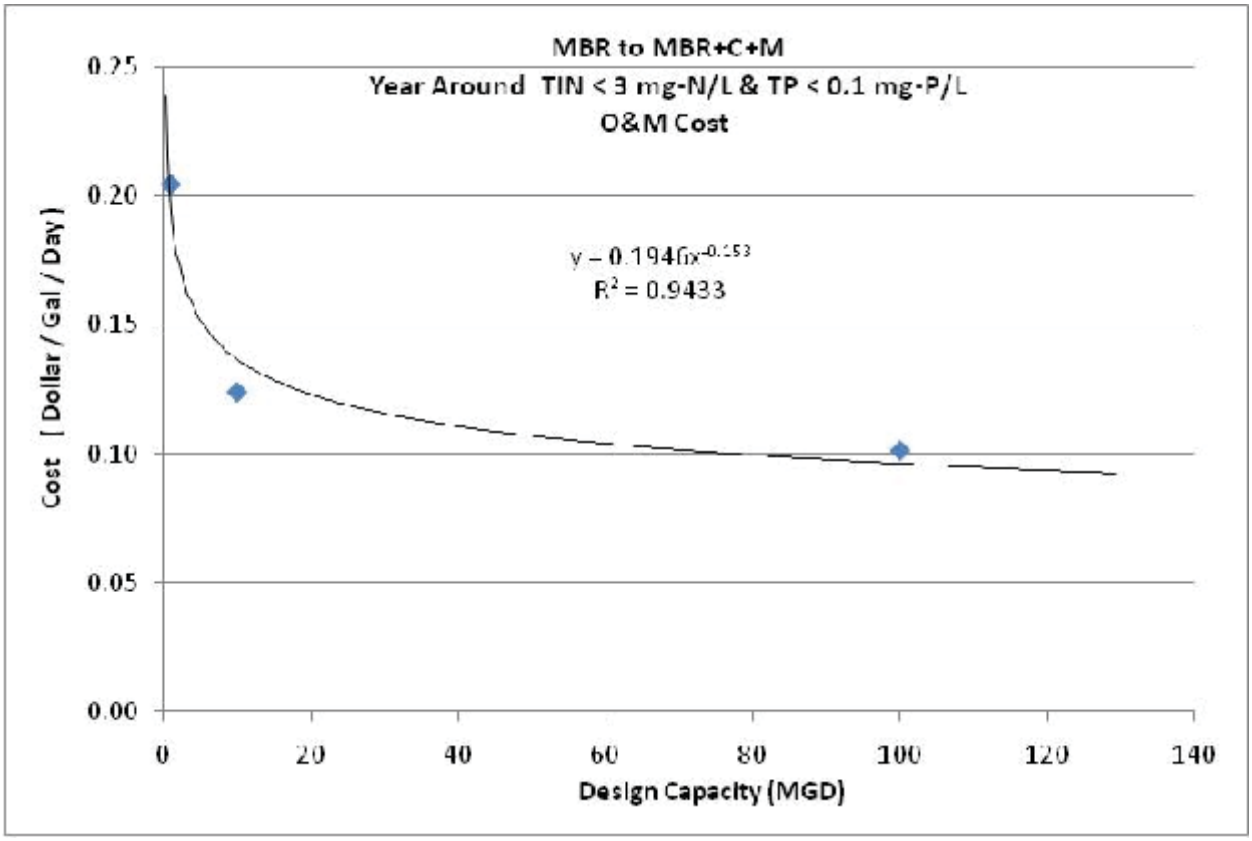


Figure 16-16. O&M Cost per Plant Capacity for MBR Plant Upgraded for Objective F Year-Round

TABLE 16-16.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE F YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$99,292	$256,052	$2,069,159
2014 Incremental O&M Cost	$230,266	$1,393,462	$11,375,377
Total Annual Cost	**$329,558**	**$1,649,514**	**$13,444,536**
Annual TIN Load Reduction (lb/yr)	9,600	95,995	959,950
Annual TP Load Reduction (lb/yr)	12,483	124,830	1,248,300
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$2.11	$1.90	$1.89
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$24.78	$11.75	$9.32
TIN Cost Equation:[a]	$y = 2.584x^{-0.024}$		
TIN Cost R-Square Value:	0.7859		
TP Cost Equation:[b]	$y = 168.53x^{-0.212}$		
TP Cost R-Square Value:	0.9155		

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

16.1.6 High-Purity Oxygen Activated Sludge Plants

High-purity oxygen activated sludge plants were not evaluated for any objectives that include phosphorus removal, so no costs associated with Objective F were developed for these plants.

16.1.7 Aerated or Facultative Lagoon Plants

Table 16-17 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective F year-round for an aerated lagoon plant. Figures 16-17 and 16-18 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 16-18 and Figures 16-19 and 16-20 summarize these costs for a facultative lagoon plant. Tables 16-19 and 16-20 present the annualized unit costs for reducing nutrient loads for aerated lagoon and facultative lagoon plants, respectively.

TABLE 16-17.
ESTIMATED COST PER CAPACITY FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE F YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$27.75	$21.63	$13.88	$9.59
Incremental Annual O&M Cost per gpd of Plant Capacity	$1.49	$0.97	$0.52	$0.34

TABLE 16-18.
ESTIMATED COST PER CAPACITY FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE F YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$27.61	$21.52	$13.79	$9.54
Incremental Annual O&M Cost per gpd of Plant Capacity	$1.76	$1.20	$0.68	$0.37

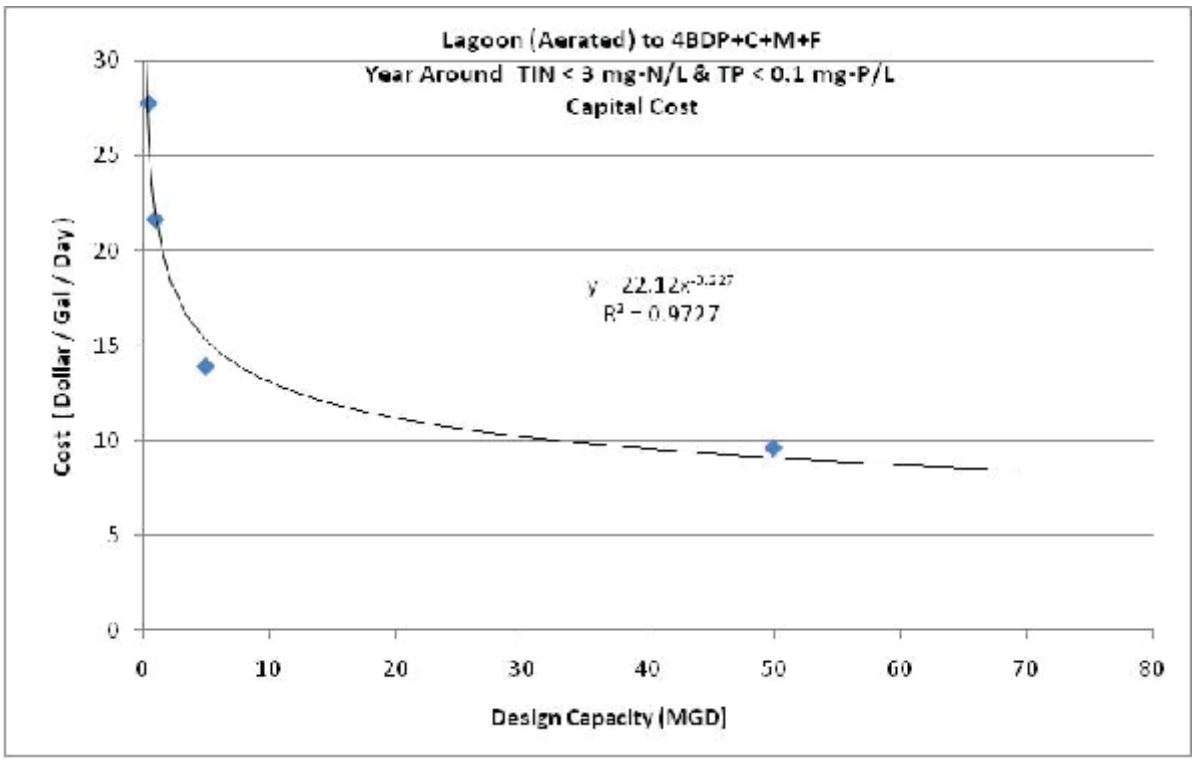


Figure 16-17. Capital Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective F Year-Round

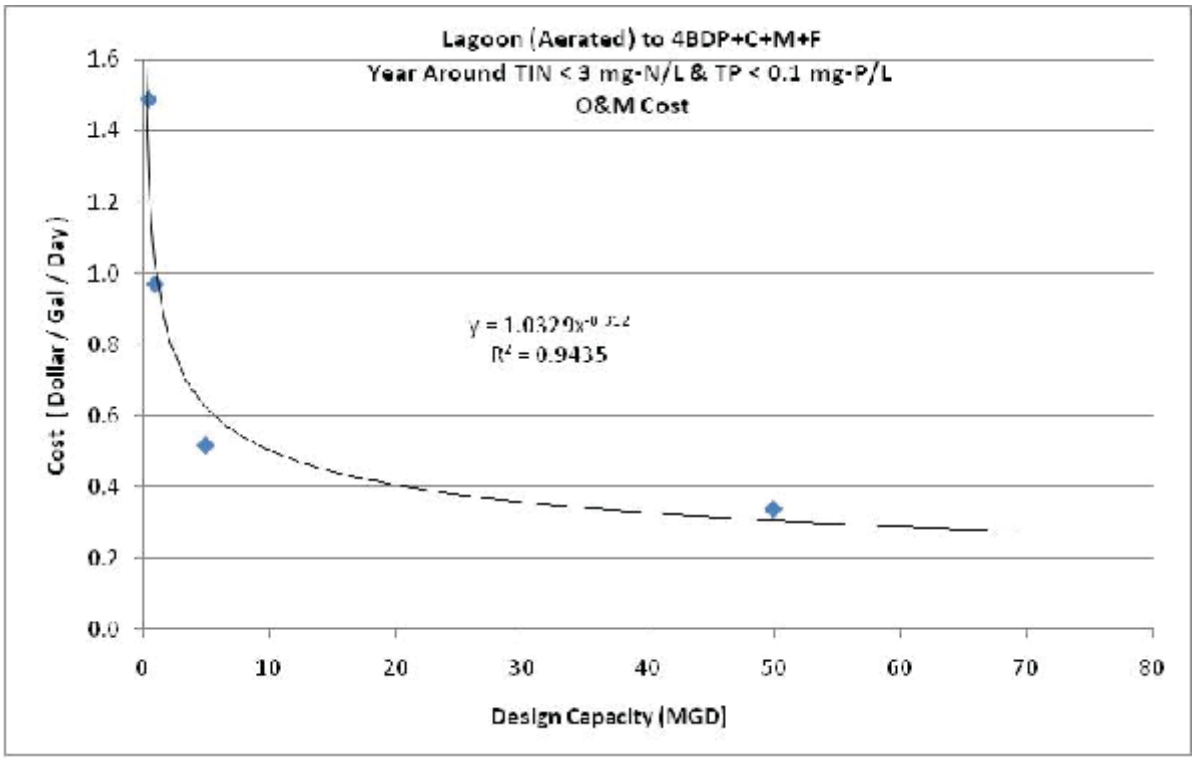


Figure 16-18. O&M Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective F Year-Round

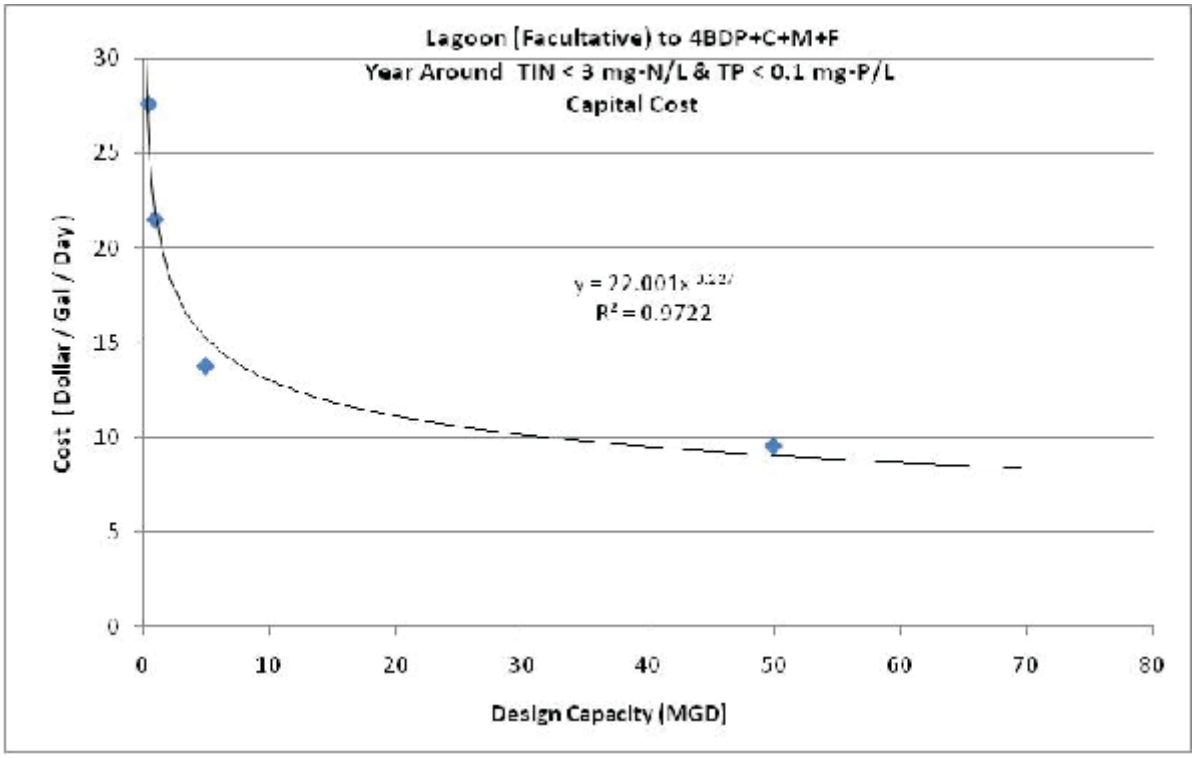


Figure 16-19. Capital Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective F Year-Round

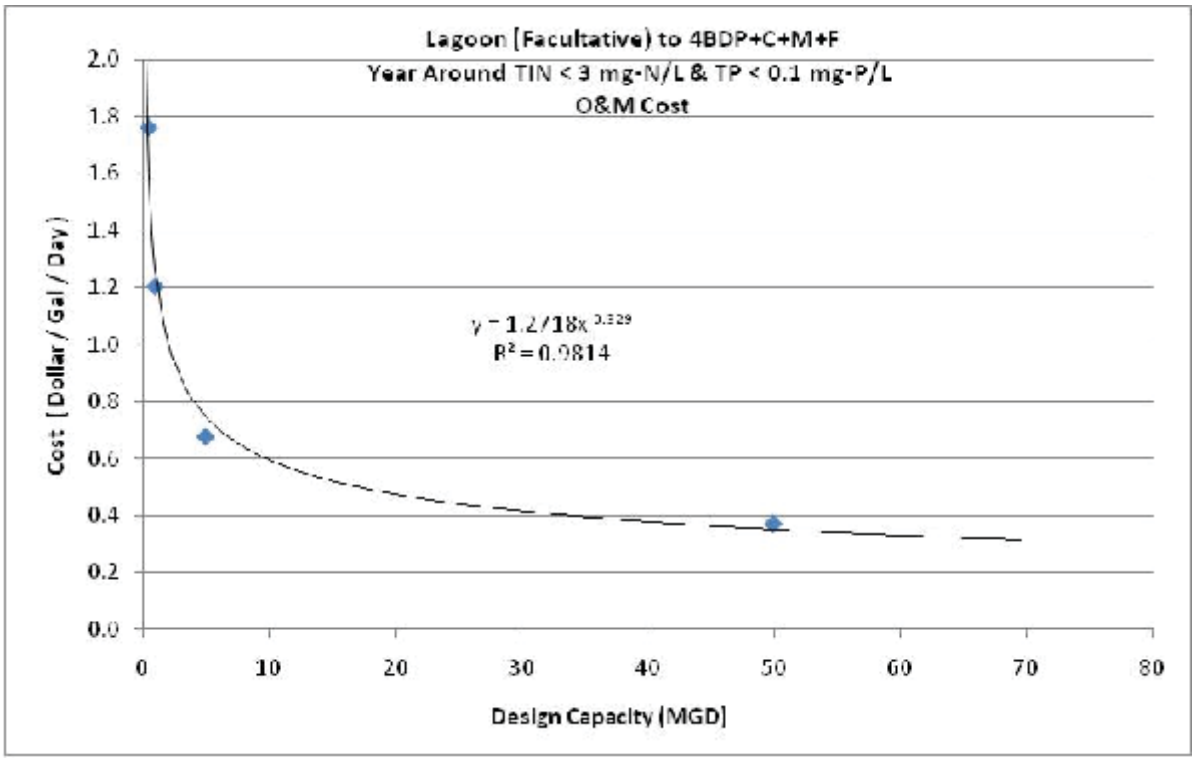


Figure 16-20. O&M Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective F Year-Round

TABLE 16-19.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE F YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$1,019,087	$1,588,845	$5,096,170	$35,210,268
2014 Incremental O&M Cost	$837,007	$1,090,989	$2,913,323	$19,071,325
Total Annual Cost	**$1,856,094**	**$2,679,834**	**$8,009,493**	**$54,281,593**
Annual TIN Load Reduction (lb/yr)	22,667	45,333	226,665	2,259,350
Annual TP Load Reduction (lb/yr)	6,570	13,140	65,700	657,000
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$61.17	$42.64	$26.34	$16.68
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$71.48	$56.84	$31.05	$25.24
TIN Cost Equation:[a]	$y = 845.78x^{-0.273}$			
TIN Cost R-Square Value:	0.9676			
TP Cost Equation:[b]	$y = 489.23x^{-0.229}$			
TP Cost R-Square Value:	0.9088			

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 16-20.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE F YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$1,014,069	$1,580,372	$5,063,018	$35,035,872
2014 Incremental O&M Cost	$990,177	$1,354,668	$3,816,150	$20,958,595
Total Annual Cost	**$2,004,245**	**$2,935,040**	**$8,879,169**	**$55,994,467**
Annual TIN Load Reduction (lb/yr)	22,667	45,333	226,665	2,259,350
Annual TP Load Reduction (lb/yr)	6,570	13,140	65,700	657,000
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$67.74	$48.28	$30.20	$17.42
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$71.35	$56.81	$30.96	$25.33
TIN Cost Equation:[a]	$y = 1101.9x^{-0.286}$			
TIN Cost R-Square Value:	0.9844			
TP Cost Equation:[b]	$y = 483.82x^{-0.228}$			
TP Cost R-Square Value:	0.906			

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

16.2 SEASONAL NUTRIENT REMOVAL

16.2.1 Extended Aeration Plants

Table 16-21 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective F seasonally for an extended aeration plant using mechanical aeration. Figures 16-21 and 16-22 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 16-22 and Figures 16-23 and 16-24 summarize these costs for an extended aeration plant using diffuser aeration. Tables 16-23 and 16-24 present the annualized unit costs for reducing nutrient loads for mechanical aeration and diffuser aeration plants, respectively.

TABLE 16-21.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE F SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$7.02	$3.56	$2.98
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.53	$0.19	$0.11

TABLE 16-22.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE F SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$3.29	$2.07	$1.11
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.34	$0.13	$0.08

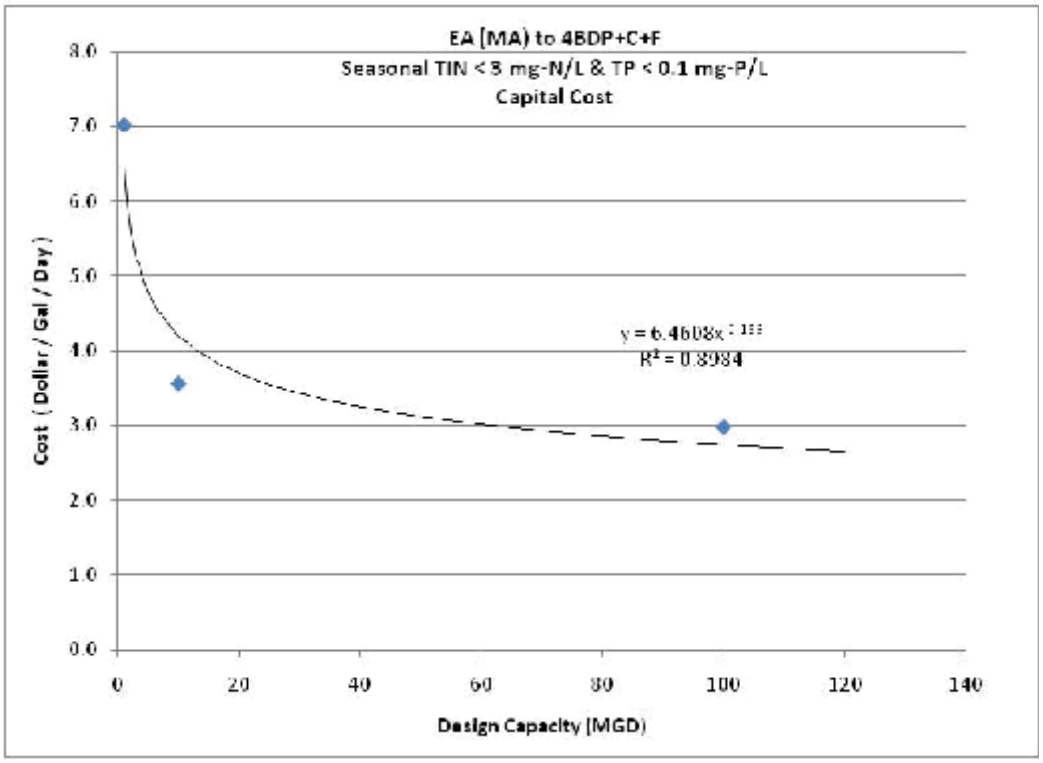


Figure 16-21. Capital Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective F Seasonally

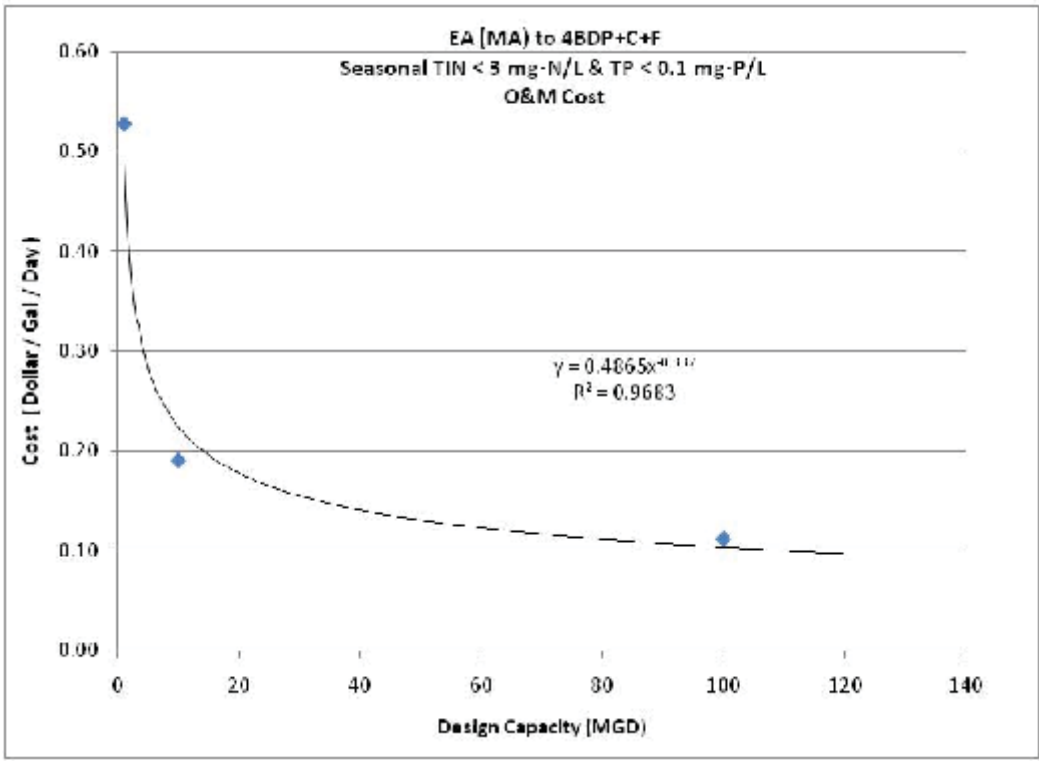


Figure 16-22. O&M Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective F Seasonal

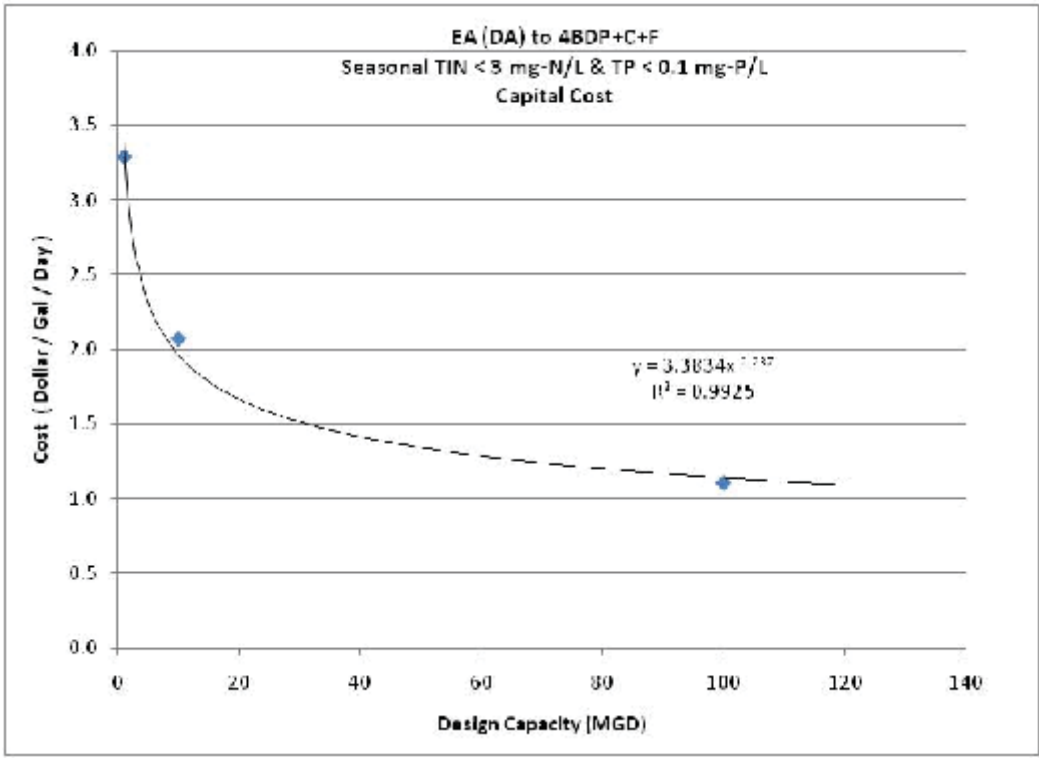


Figure 16-23. Capital Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective F Seasonally

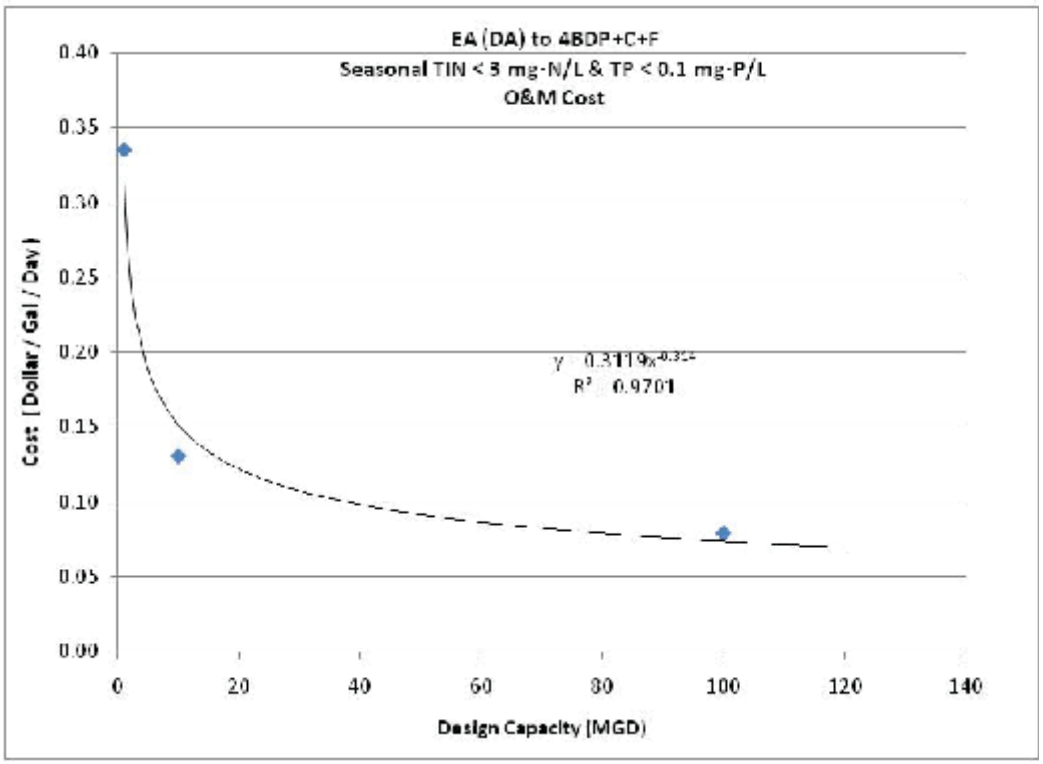


Figure 16-24. O&M Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective F Seasonal

TABLE 16-23.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EA (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE F SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$515,745	$2,615,929	$21,868,804
2014 Incremental O&M Cost	$593,790	$2,145,974	$12,606,374
Total Annual Cost	**$1,109,535**	**$4,761,903**	**$34,475,178**
Annual TIN Load Reduction (lb/yr)	23,506	235,060	2,350,600
Annual TP Load Reduction (lb/yr)	6,388	63,875	638,750
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$32.92	$11.05	$7.43
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$52.57	$33.87	$26.63
TIN Cost Equation:[a]			$y = 762.22x^{-0.324}$
TIN Cost R-Square Value:			0.9322
TP Cost Equation:[b]			$y = 185.49x^{-0.148}$
TP Cost R-Square Value:			0.9722

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 16-24.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EA ((DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE F SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$241,811	$1,521,842	$8,131,012
2014 Incremental O&M Cost	$377,749	$1,472,582	$8,907,389
Total Annual Cost	**$619,560**	**$2,994,424**	**$17,038,401**
Annual TIN Load Reduction (lb/yr)	23,488	234,878	2,348,775
Annual TP Load Reduction (lb/yr)	6,388	63,875	638,750
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$11.90	$3.35	$0.53
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$53.22	$34.58	$24.74
TIN Cost Equation:[a]			$y = 11759x^{-0.676}$
TIN Cost R-Square Value:			0.9887
TP Cost Equation:[b]			$y = 224.95x^{-0.166}$
TP Cost R-Square Value:			0.9948

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

16.2.2 Conventional Activated Sludge Plants

Table 16-25 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective F seasonally for a conventional activated sludge plant. Figures 16-25 and 16-26 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 16-26 presents the annualized unit costs for reducing nutrient loads.

TABLE 16-25.
ESTIMATED COST PER CAPACITY FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE F SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$5.06	$2.63	$2.08
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.45	$0.19	$0.13

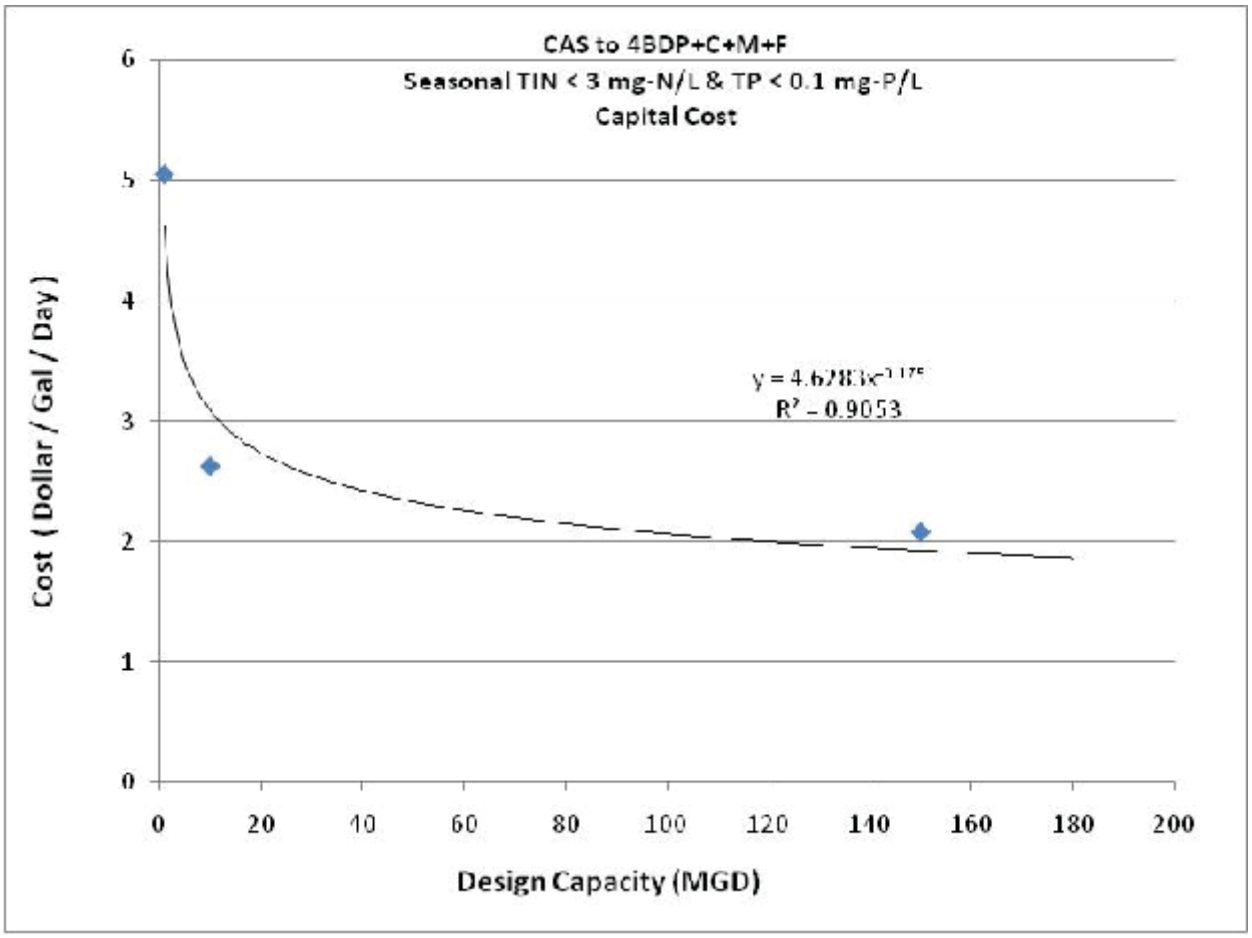


Figure 16-25. Capital Cost per Plant Capacity for CAS Plant Upgraded for Objective F Seasonally

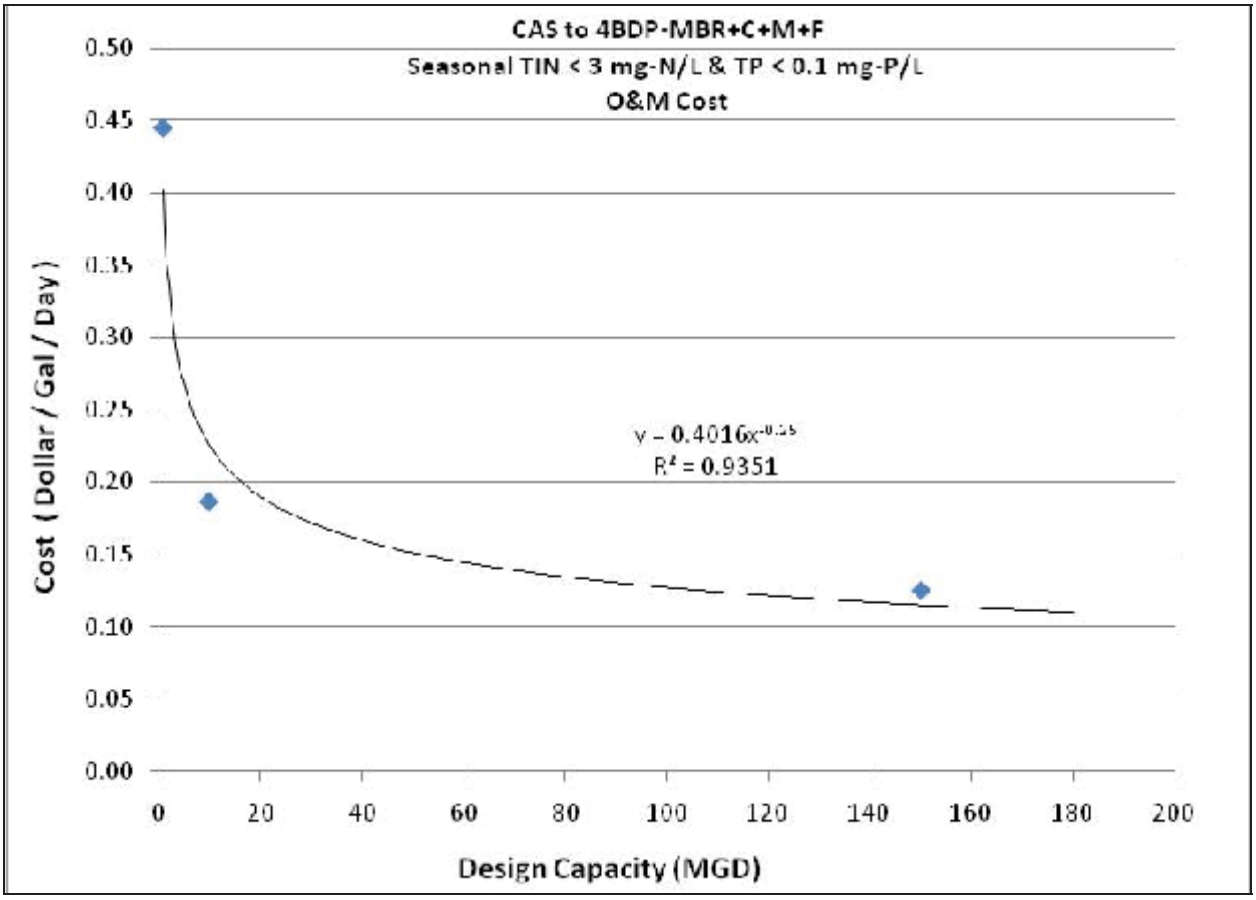


Figure 16-26. O&M Cost per Plant Capacity for CAS Plant Upgraded for Objective F Seasonal

TABLE 16-26.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE F SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$371,402	$1,928,646	$22,872,331
2014 Incremental O&M Cost	$501,029	$2,102,692	$21,173,550
Total Annual Cost	**$872,431**	**$4,031,339**	**$44,045,881**
Annual TIN Load Reduction (lb/yr)	23,068	230,680	3,460,200
Annual TP Load Reduction (lb/yr)	6,588	65,883	988,238
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$19.33	$7.56	$5.45
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$64.74	$34.73	$25.50
TIN Cost Equation:[a]	$y = 207.09x^{-0.249}$		
TIN Cost R-Square Value:	0.9019		
TP Cost Equation:[b]	$y = 304x^{-0.184}$		
TP Cost R-Square Value:	0.9441		

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

16.2.3 Sequencing Batch Reactor Plants

Table 16-27 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective F seasonally for an SBR plant. Figures 16-27 and 16-28 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 16-28 presents the annualized unit costs for reducing nutrient loads.

TABLE 16-27.
ESTIMATED COST PER CAPACITY FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE F SEASONALLY

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Capital Cost per gpd of Plant Capacity	$4.44	$2.48	$1.41
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.72	$0.29	$0.12

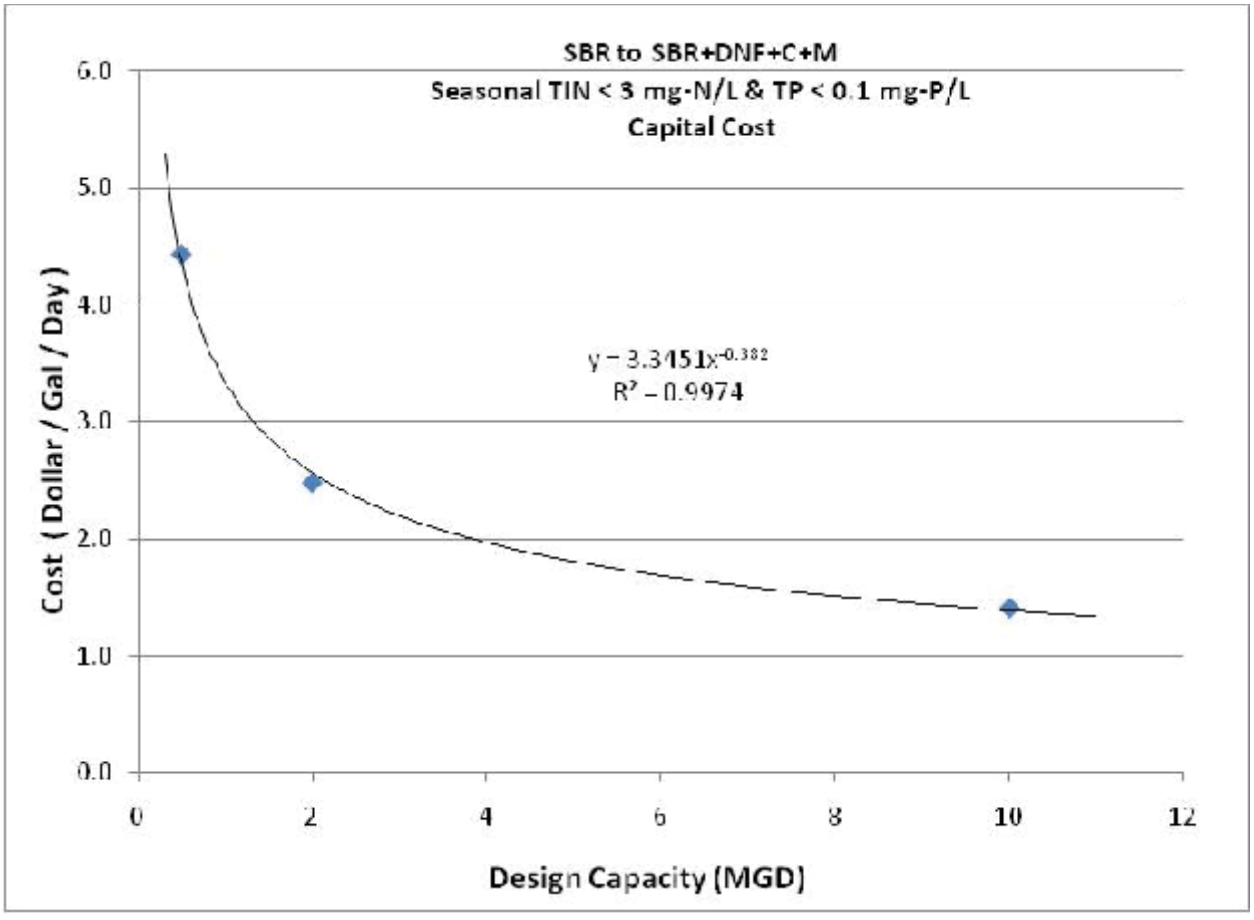


Figure 16-27. Capital Cost per Plant Capacity for SBR Plant Upgraded for Objective F Seasonally

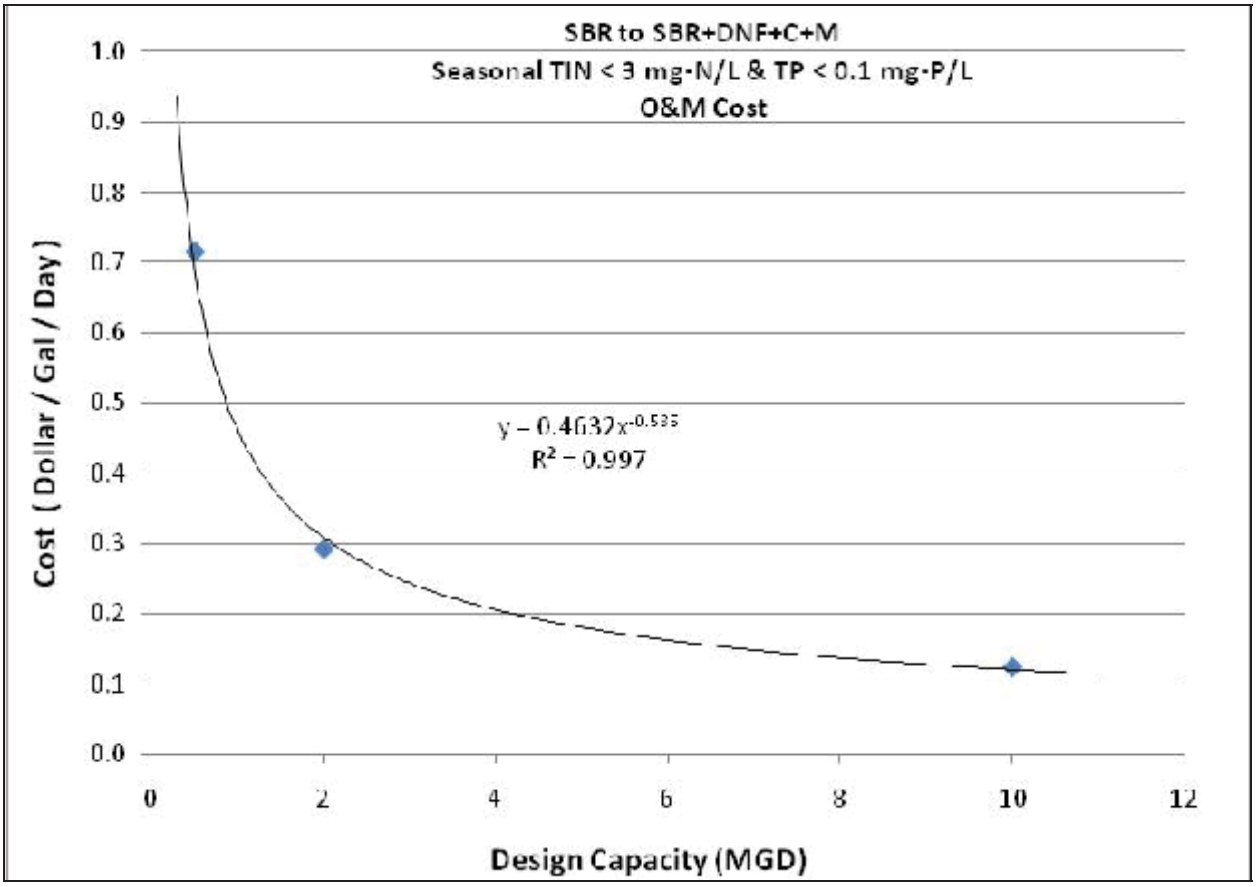


Figure 16-28. O&M Cost per Plant Capacity for SBR Plant Upgraded for Objective F Seasonal

TABLE 16-28.
UNIT NUTRIENT REMOVAL COSTS FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE F SEASONALLY

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Annualized Capital Cost	$163,045	$364,500	$1,034,896
2014 Incremental O&M Cost	$402,993	$657,438	$1,390,054
Total Annual Cost	**$566,038**	**$1,021,937**	**$2,424,950**
Annual TIN Load Reduction (lb/yr)	475	1,898	9,490
Annual TP Load Reduction (lb/yr)	1,487	5,950	29,748
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$788.41	$309.62	$114.38
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$129.05	$72.99	$45.03
TIN Cost Equation:[a]			$y = 41108x^{-0.644}$
TIN Cost R-Square Value:			0.9994
TP Cost Equation:[b]			$y = 1616x^{-0.35}$
TP Cost R-Square Value:			0.9918

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

16.2.4 Trickling Filter, Trickling Filter/Solids Contact and Rotating Biological Contactor Plants

Table 16-29 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective F seasonally for a trickling filter plant. Figures 16-29 and 16-30 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 16-30 and Figures 16-31 and 16-32 summarize these costs for a trickling filter/solids contact plant. Table 16-31 and Figures 16-33 and 16-34 summarize these costs for an RBC plant. Tables 16-32, 16-33 and 16-34 present the annualized unit costs for reducing nutrient loads for TF, TF/SC and RBC plants, respectively.

TABLE 16-29.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER PLANT TO ACHIEVE OBJECTIVE F SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$7.11	$4.16	$2.59
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.51	$0.21	$0.13

TABLE 16-30.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER/SOLIDS CONTACT PLANT TO ACHIEVE OBJECTIVE F SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$5.37	$3.47	$2.18
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.38	$0.17	$0.10

TABLE 16-31.
ESTIMATED COST PER CAPACITY FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE F SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$7.13	$4.18	$2.63
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.57	$0.23	$0.14

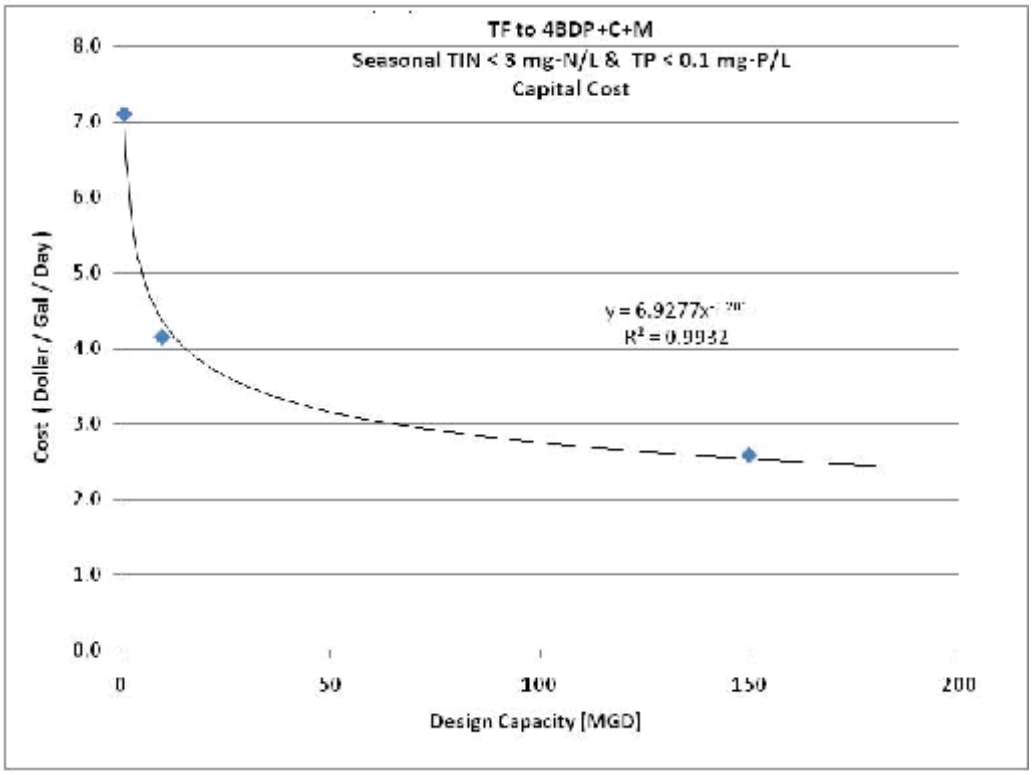


Figure 16-29. Capital Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective F Seasonally

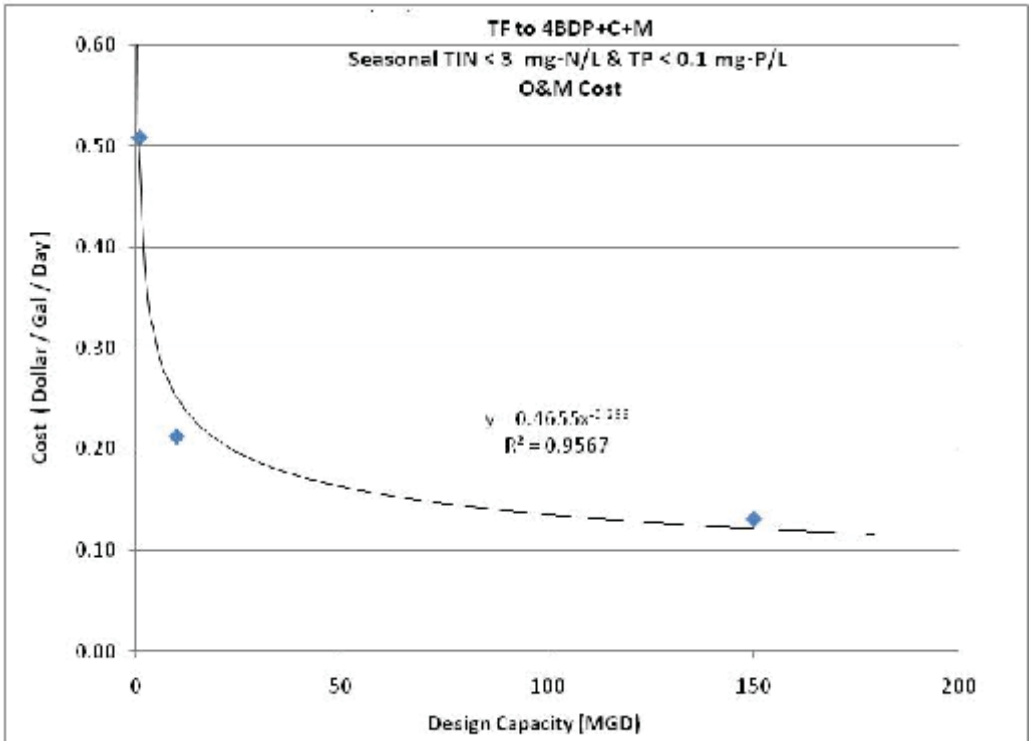


Figure 16-30. O&M Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective F Seasonal

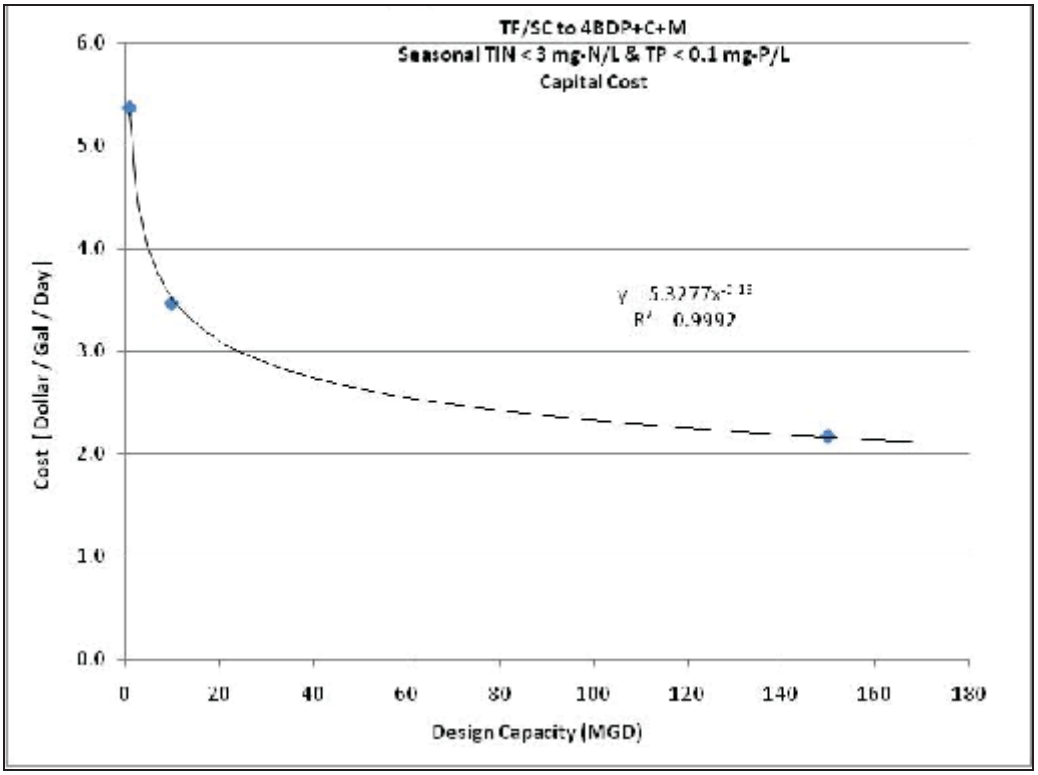


Figure 16-31. Capital Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective F Seasonally

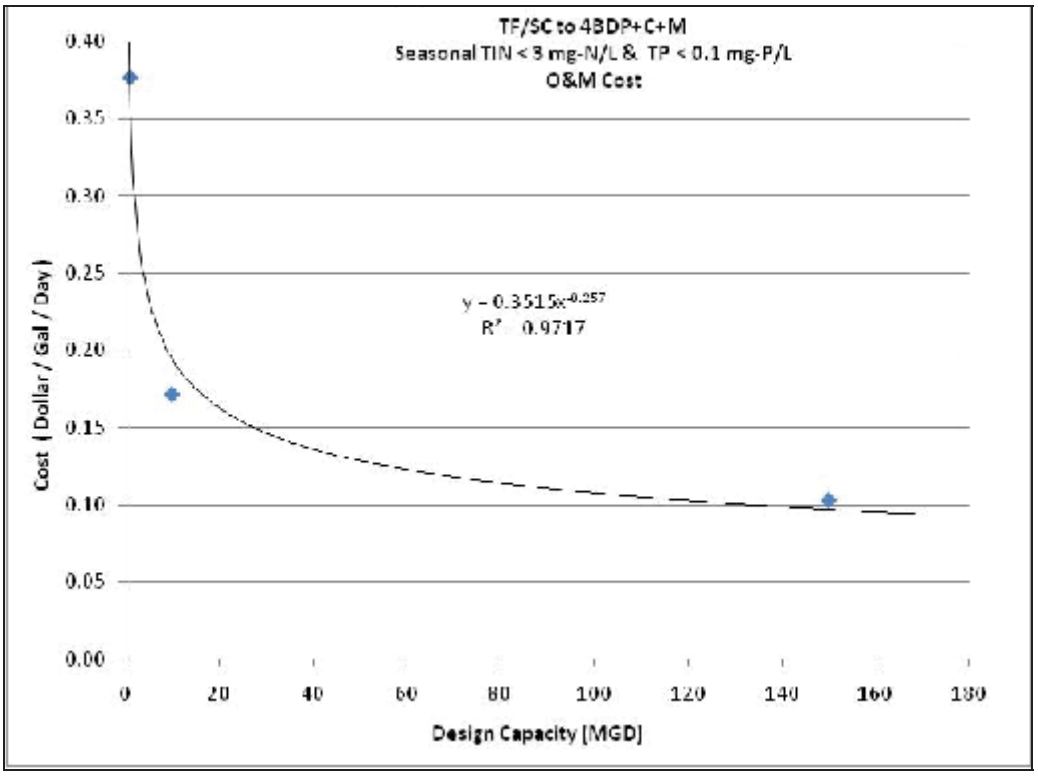


Figure 16-32. O&M Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective F Seasonal

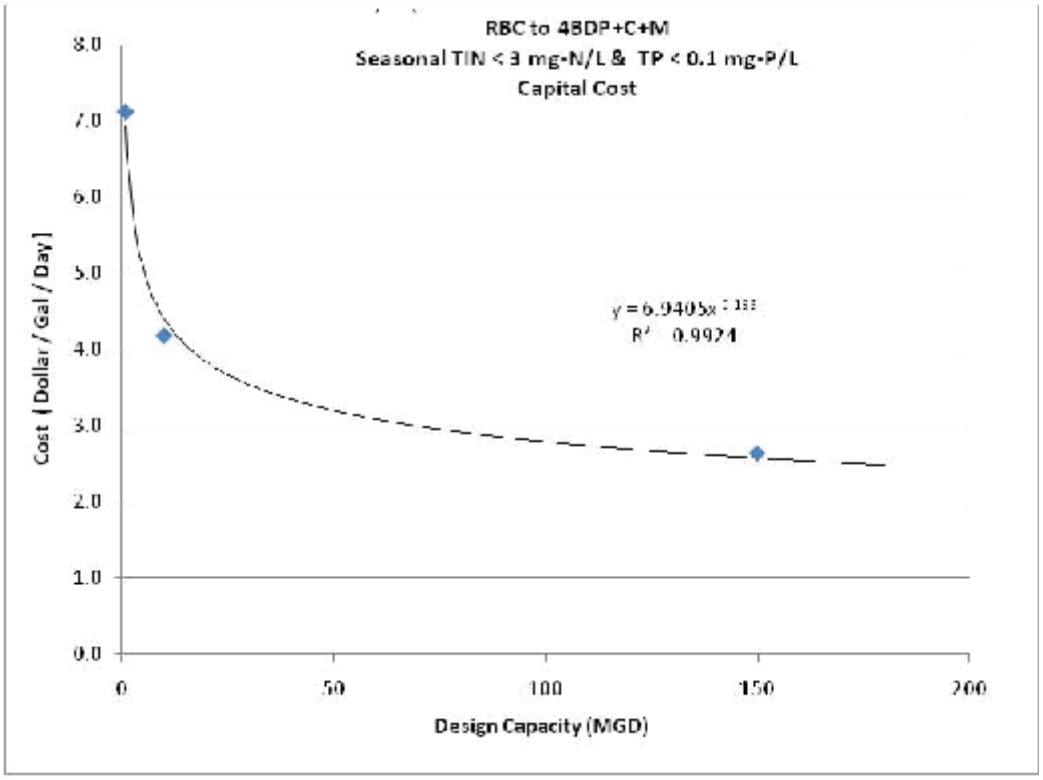


Figure 16-33. Capital Cost per Plant Capacity for RBC Plant Upgraded for Objective F Seasonally

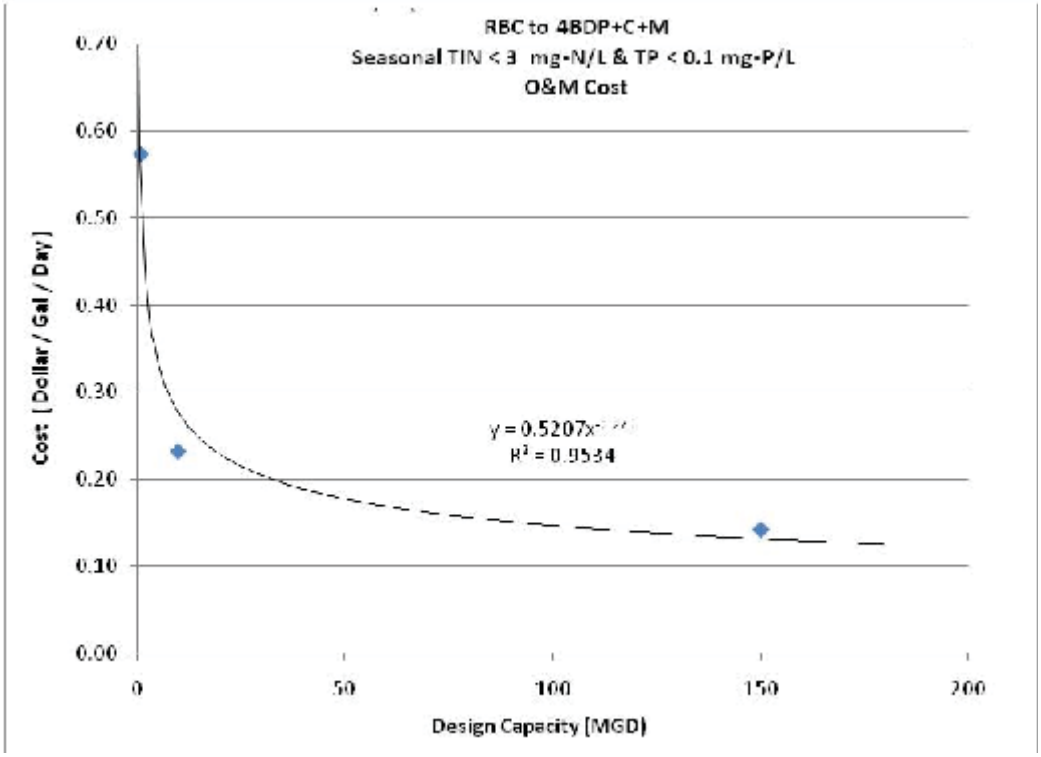


Figure 16-34. O&M Cost per Plant Capacity for RBC Plant Upgraded for Objective F Seasonal

TABLE 16-32.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TF PLANT TO ACHIEVE OBJECTIVE F SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$522,245	$3,054,433	$28,541,079
2014 Incremental O&M Cost	$572,876	$2,394,087	$22,094,779
Total Annual Cost	**$1,095,120**	**$5,448,520**	**$50,635,858**
Annual TIN Load Reduction (lb/yr)	23,068	230,680	3,460,200
Annual TP Load Reduction (lb/yr)	6,588	65,883	988,238
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$29.59	$14.12	$7.66
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$62.60	$33.27	$24.40
TIN Cost Equation:[a]	$y = 420.51x^{-0.268}$		
TIN Cost R-Square Value:	0.9897		
TP Cost Equation:[b]	$y = 298.79x^{-0.186}$		
TP Cost R-Square Value:	0.9428		

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 16-33.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TF/SC PLANT TO ACHIEVE OBJECTIVE F SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$394,434	$2,547,369	$23,973,880
2014 Incremental O&M Cost	$423,796	$1,926,775	$17,335,002
Total Annual Cost	**$818,230**	**$4,474,144**	**$41,308,882**
Annual TIN Load Reduction (lb/yr)	23,068	230,680	3,460,200
Annual TP Load Reduction (lb/yr)	6,588	65,883	988,238
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$17.42	$9.77	$4.96
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$63.19	$33.69	$24.43
TIN Cost Equation:[a]	$y = 216.12x^{-0.251}$		
TIN Cost R-Square Value:	1		
TP Cost Equation:[b]	$y = 306.92x^{-0.188}$		
TP Cost R-Square Value:	0.9474		

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 16-34.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE F SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$523,808	$3,071,873	$28,994,343
2014 Incremental O&M Cost	$644,576	$2,608,552	$24,009,832
Total Annual Cost	**$1,168,384**	**$5,680,425**	**$53,004,176**
Annual TIN Load Reduction (lb/yr)	23,068	230,680	3,460,200
Annual TP Load Reduction (lb/yr)	6,588	65,883	988,238
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$32.63	$15.09	$8.41
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$63.08	$33.40	$24.20
TIN Cost Equation:[a]	$y = 461.44x^{-0.269}$		
TIN Cost R-Square Value:	0.9842		
TP Cost Equation:[b]	$y = 310.09x^{-0.189}$		
TP Cost R-Square Value:	0.9465		

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

16.2.5 Membrane Biological Reactor Plants

Table 16-35 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective F seasonally for an MBR plant. Figures 16-35 and 16-36 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 16-36 presents the annualized unit costs for reducing nutrient loads.

TABLE 16-35.
ESTIMATED COST PER CAPACITY FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE F SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.22	$0.27	$0.03
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.16	$0.08	$0.06

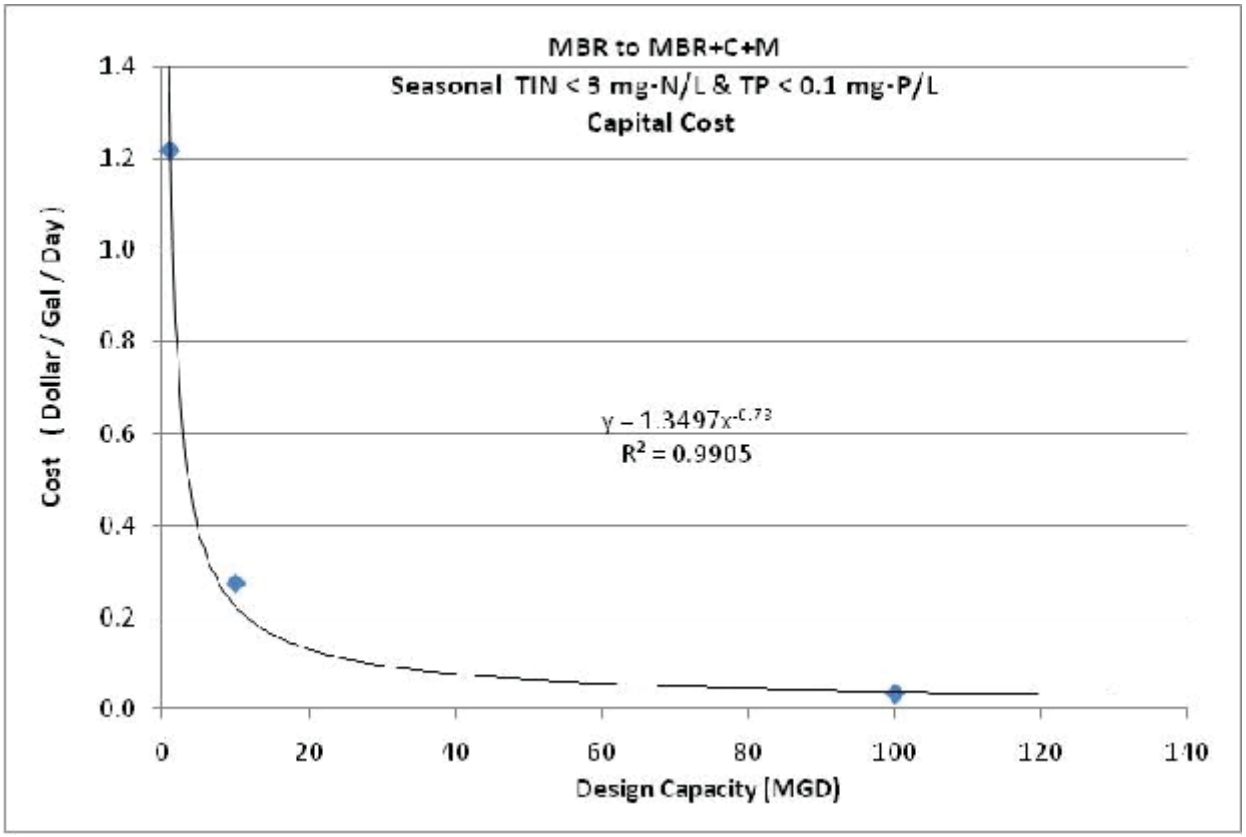


Figure 16-35. Capital Cost per Plant Capacity for MBR Plant Upgraded for Objective F Seasonally

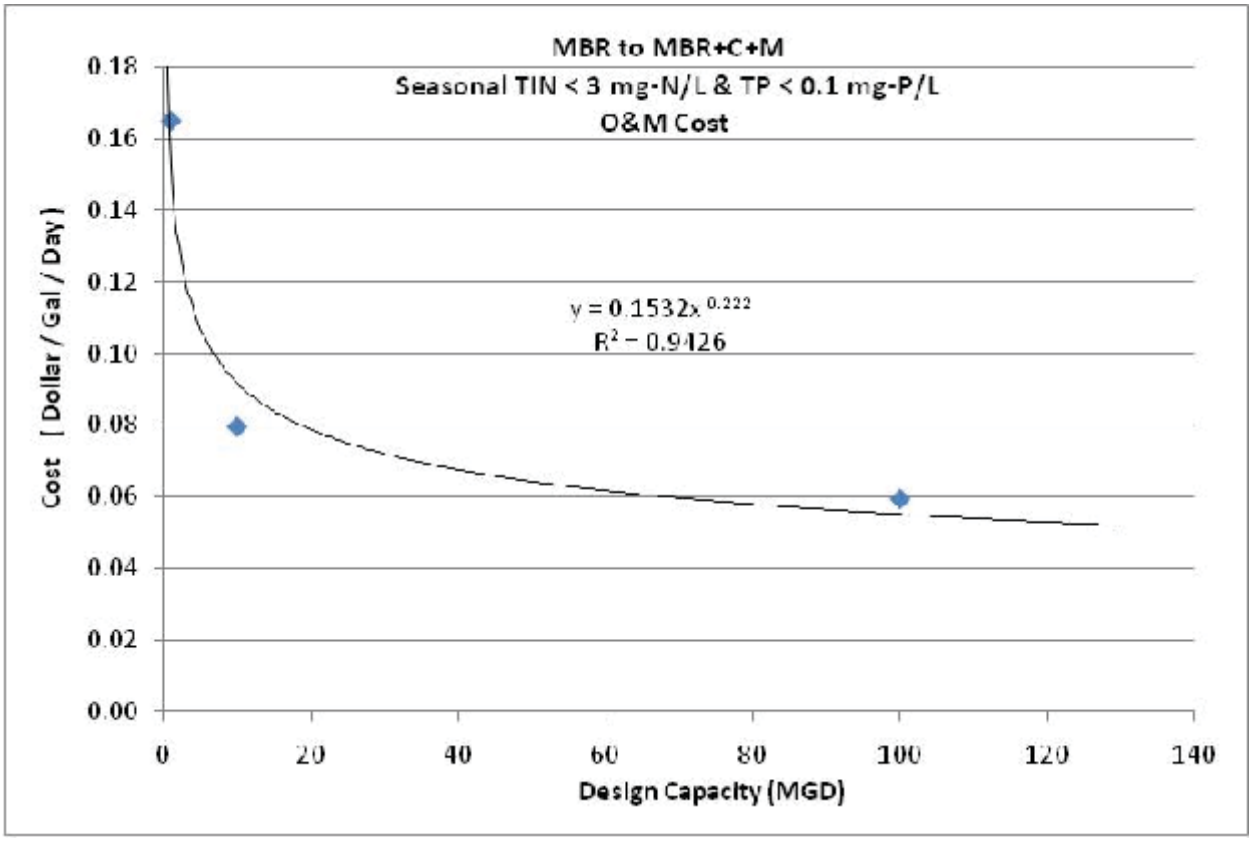


Figure 16-36. O&M Cost per Plant Capacity for MBR Plant Upgraded for Objective F Seasonal

TABLE 16-36.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE F SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$89,545	$201,723	$246,882
2014 Incremental O&M Cost	$185,518	$893,767	$6,667,739
Total Annual Cost	**$275,063**	**$1,095,490**	**$6,914,621**
Annual TIN Load Reduction (lb/yr)	3,869	38,690	386,900
Annual TP Load Reduction (lb/yr)	6,169	61,685	616,850
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$4.27	$3.79	$3.76
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$41.91	$15.38	$8.85
TIN Cost Equation:[a]	$y = 5.2658x^{-0.028}$		
TIN Cost R-Square Value:	0.7967		
TP Cost Equation:[b]	$y = 740.77x^{-0.338}$		
TP Cost R-Square Value:	0.9729		

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

16.2.6 High-Purity Oxygen Activated Sludge Plants

High-purity oxygen activated sludge plants were not evaluated for any objectives that include phosphorus removal, so no costs associated with Objective F were developed for these plants.

16.2.7 Aerated or Facultative Lagoon Plants

Table 16-37 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective F seasonally for an aerated lagoon plan. Figures 16-37 and 16-38 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 16-38 and Figures 16-39 and 16-40 summarize these costs for a facultative lagoon plant. Tables 16-39 and 16-40 present the annualized unit costs for reducing nutrient loads for aerated lagoon an facultative lagoon plants, respectively.

TABLE 16-37.
ESTIMATED COST PER CAPACITY FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE F SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$26.26	$19.09	$12.68	$8.23
Incremental Annual O&M Cost per gpd of Plant Capacity	$1.31	$0.82	$0.39	$0.20

TABLE 16-38.
ESTIMATED COST PER CAPACITY FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE F SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$26.12	$18.97	$12.59	$8.19
Incremental Annual O&M Cost per gpd of Plant Capacity	$1.58	$1.05	$0.55	$0.23

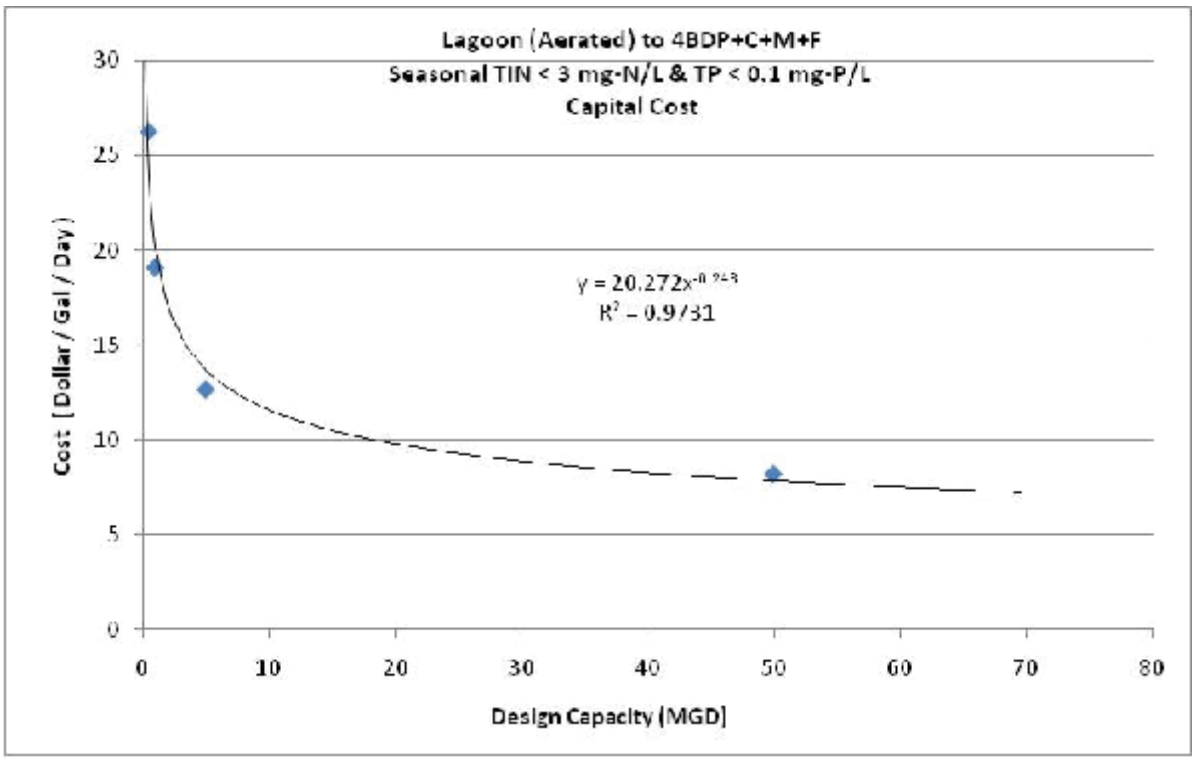


Figure 16-37. Capital Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective F Seasonally

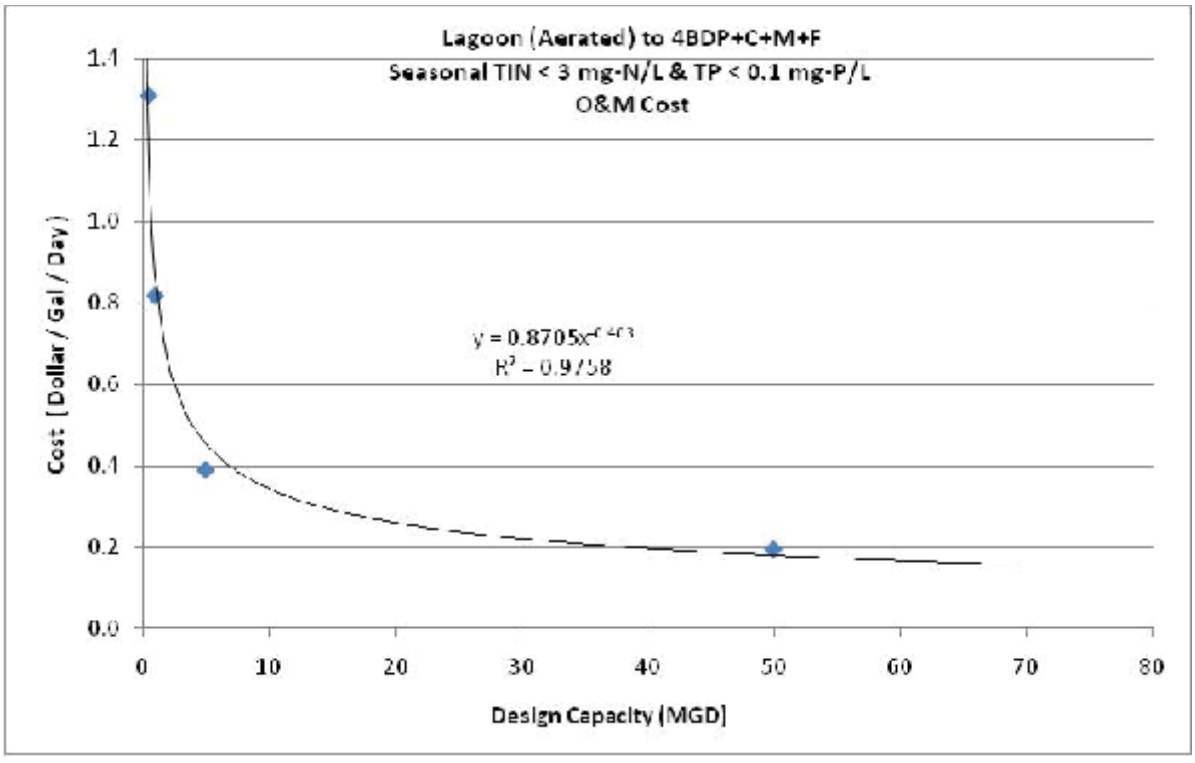


Figure 16-38. O&M Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective F Seasonal

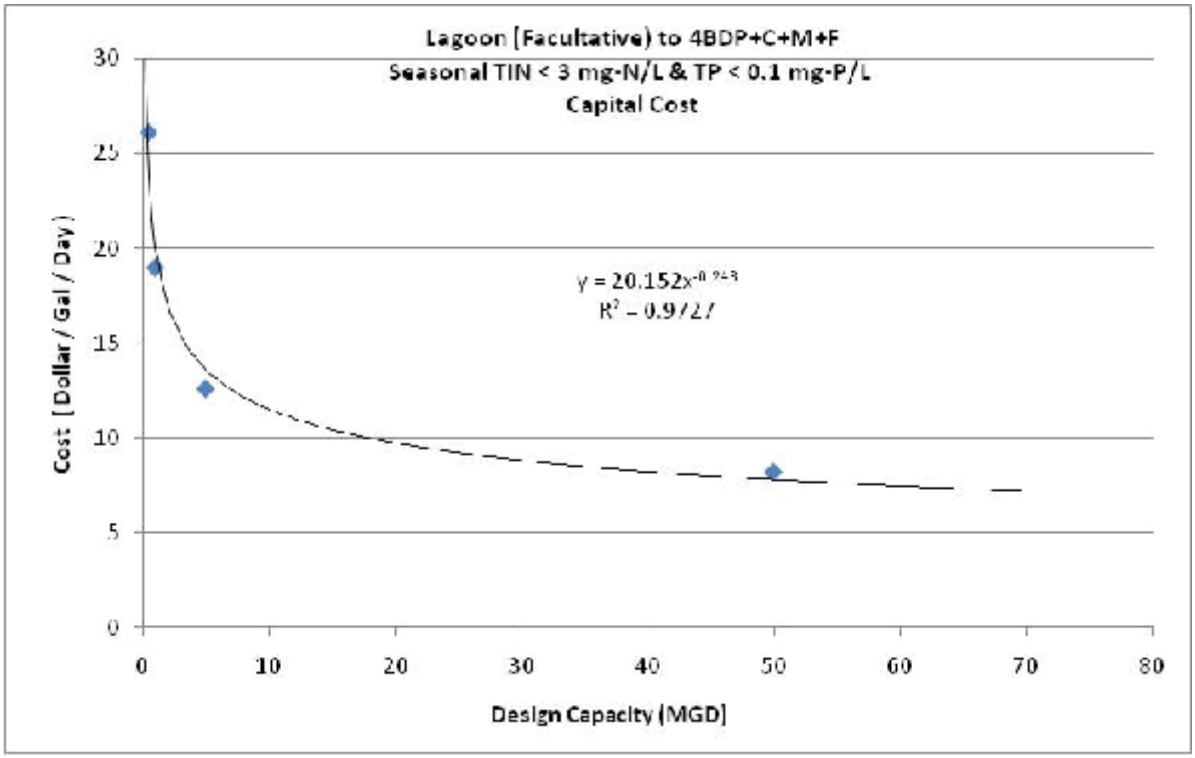


Figure 16-39. Capital Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective F Seasonally

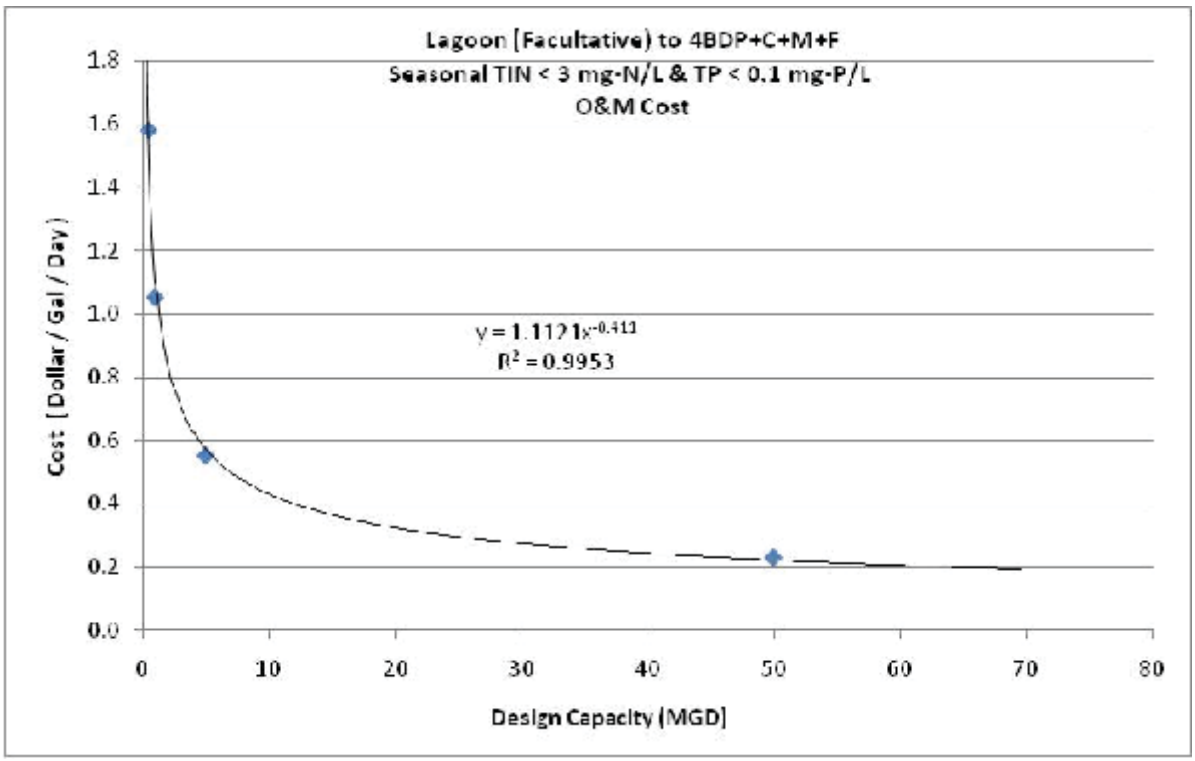


Figure 16-40. O&M Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective F Seasonal

TABLE 16-39.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE F SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$964,506	$1,401,842	$4,654,926	$30,238,589
2014 Incremental O&M Cost	$736,744	$920,616	$2,199,768	$11,006,857
Total Annual Cost	**$1,701,250**	**$2,322,458**	**$6,854,693**	**$41,245,446**
Annual TIN Load Reduction (lb/yr)	11,634	23,269	116,344	1,153,400
Annual TP Load Reduction (lb/yr)	3,294	6,588	32,941	329,413
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$106.84	$72.87	$43.23	$24.43
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$139.09	$95.14	$55.39	$39.67
TIN Cost Equation:[a]	$y = 1775.1x^{-0.311}$			
TIN Cost R-Square Value:	0.9795			
TP Cost Equation:[b]	$y = 1023.5x^{-0.263}$			
TP Cost R-Square Value:	0.9326			

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 16-40.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE F SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$959,405	$1,393,369	$4,621,774	$30,064,193
2014 Incremental O&M Cost	$889,913	$1,184,294	$3,102,594	$12,894,127
Total Annual Cost	**$1,849,319**	**$2,577,664**	**$7,724,396**	**$42,958,320**
Annual TIN Load Reduction (lb/yr)	11,634	23,269	116,344	1,153,400
Annual TP Load Reduction (lb/yr)	3,294	6,588	32,941	329,413
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$120.94	$85.15	$51.92	$26.48
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$134.27	$90.52	$51.11	$37.70
TIN Cost Equation:[a]	$y = 2288.9x^{-0.321}$			
TIN Cost R-Square Value:	0.9921			
TP Cost Equation:[b]	$y = 1003.4x^{-0.267}$			
TP Cost R-Square Value:	0.9193			

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)
b. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

CHAPTER 17.
CUMULATIVE COST IMPACT SUMMARY

17.1 CUMULATIVE STATEWIDE COST

Cost models presented in previous chapters of this report represent expected costs for upgrading individual treatment plants to meet a range of potential objectives for limiting nitrogen and phosphorus in effluent discharged to surface waters. If the State of Washington were to adopt regulatory guidelines establishing such limits, then municipal treatment plants throughout the state would need to perform upgrades, with potentially significant statewide cost implications.

In order to assess the magnitude of such potential future cost impacts, the cost models developed for each of the respective nutrient removal objectives (i.e., Chapters 11-16) were applied to Ecology's list of all municipal treatment plants operating in Washington. As described in Chapter 2, there are currently 304 such plants operating in the state. Using a list of the treatment type and maximum-month capacity for each of these plants, the upgrade capital and O&M cost models identified in the previous chapters for several capacities for each type of plant were used to estimate upgrade costs for each specific plant operating in the state. These costs were then totaled by treatment type and on a statewide basis. Tables 17-1, 17-2 and 17-3 present the results for capital cost, annual O&M cost and 20-year annualized total cost (assuming a 3-percent discount rate), respectively. The expected accuracy range for these estimates is +100% to -50% percent. Actual costs for a specific facility would have to be determined through a site specific engineering study.

17.2 POTENTIAL SEWER RATE IMPACTS

Based on the cumulate statewide costs estimated as described above, an evaluation was performed to estimate the likely cost impact on sewer rates per household. The monthly increase was calculated from the annualized statewide costs, assuming a statewide population of about 5.5 million, an average household size of 2.5 persons, a per capita maximum-month wastewater flow of 160 gallons, and a future number of households at design capacity equal to 1.33 times the current number of households. The resulting rate impact estimates are shown in Table 17-4.

17.3 WATERSHED-WIDE COSTS FOR NUTRIENT REMOVAL

For planning purposes, the Washington Department of Ecology has divided the state into 62 Water Resource Inventory Areas (WRIAs), representing the watershed, or drainage area, of all major water bodies in the state (see Figure 17-1). Water quality assessments and measures to address water quality problems often are developed based on these watershed designations, because the WRIAs represent all the area potentially contributing nutrients and other contaminants to affected water bodies. Therefore, if a given water body is experiencing water quality problems related to high levels of nitrogen or phosphorus, then nutrient discharge limits might be established that apply to all dischargers within that water body's WRIA. For this reason, it is useful to estimate the potential cost of upgrading all municipal treatment plants in each WRIA to achieve the various nutrient removal objectives. These estimates were made using the same approach described above for the statewide cost estimates. Tables 17-5 and 17-6 present the results for capital cost and annual O&M cost. Additional detail on costs in each WRIA is provided in Appendix D. The expected accuracy range for these estimates is +100% to -50% percent. Actual costs for a specific facility would have to be determined through a site specific engineering study.

TABLE 17-1.
ESTIMATED CAPITAL COSTS FOR NUTRIENT REMOVAL UPGRADES OF ALL TREATMENT PLANTS IN WASHINGTON

	Obj. A	Obj. B	Obj. C	Obj. D	Obj. E	Obj. F
Effluent TIN Limit (mg/L):	<8	<3	—	—	<8	<3
Effluent TP Limit (mg/L):	—	—	<1	<0.1	<1	<0.1
Existing Plant Type	Estimated Capital Cost ($ millions, 2010)					
Year-Round Nutrient Removal						
Extended Aeration (Mechanical Aeration)	204	239	29	133	221	360
Extended Aeration (Diffused Aeration)	4	7	3	11	5	16
Extended Aeration (with Biological Nutrient Removal)	29	128	75	328	94	414
Conventional Activated Sludge	1625	1773	142	559	1725	2253
Sequencing Batch Reactor	7	28	18	54	18	76
Trickling Filter	177	195	15	58	186	246
Rotating Biological Contactor	140	155	13	47	148	197
Trickling Filter/Solids Contact	193	207	15	59	193	252
Membrane Bioreactor	0	0	11	10	11	11
Lagoons (Aerated)	773	797	163	234	836	931
Lagoons (Facultative)	170	182	40	62	184	218
High Purity Oxygen	942	1134	N/A	N/A	942(1)	1134(1)
Statewide Total	**$4,264**	**$4,844**	**$522**	**$1,555**	**$4,564**	**$6,107**
Dry-Season-Only Nutrient Removal						
Extended Aeration (Mechanical Aeration)	192	217	28	84	227	308
Extended Aeration (Diffused Aeration)	2	5	3	7	6	11
Extended Aeration (with Biological Nutrient Removal)	38	76	76	252	66	272
Conventional Activated Sludge	564	629	185	429	660	1032
Sequencing Batch Reactor	6	25	18	46	18	66
Trickling Filter	96	105	18	42	102	138
Rotating Biological Contactor	76	84	15	33	82	111
Trickling Filter/Solids Contact	88	93	20	46	88	127
Membrane Bioreactor	0	0	10	10	10	10
Lagoons (Aerated)	773	797	163	234	836	931
Lagoons (Facultative)	164	168	35	50	177	197
High Purity Oxygen	363	477	N/A	N/A	363(1)	477(1)
Statewide Total	**$2,360**	**$2,674**	**$570**	**$1,233**	**$2,635**	**$3,680**

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Note: (1) costs are for nitrogen removal only

TABLE 17-2.
ESTIMATED ANNUAL O&M COSTS FOR NUTRIENT REMOVAL UPGRADES OF ALL TREATMENT PLANTS IN WASHINGTON

	Obj. A	Obj. B	Obj. C	Obj. D	Obj. E	Obj. F
Effluent TIN Limit (mg/L):	<8	<3	—	—	<8	<3
Effluent TP Limit (mg/L):	—	—	<1	<0.1	<1	<0.1
Existing Plant Type	Estimated Annual O&M Cost ($ millions, 2010)					
Year-Round Nutrient Removal						
Extended Aeration (Mechanical Aeration)	0	13	9	14	16	26
Extended Aeration (Diffused Aeration)	0	0	0	1	1	1
Extended Aeration (with Biological Nutrient Removal)	0	0	16	33	11	38
Conventional Activated Sludge	45	57	55	69	90	122
Sequencing Batch Reactor	0	9	1	3	0	12
Trickling Filter	5	7	4	6	9	12
Rotating Biological Contactor	5	6	4	4	8	11
Trickling Filter/Solids Contact	4	6	6	7	9	12
Membrane Bioreactor	0	0	1	2	1	2
Lagoons (Aerated)	24	28	10	12	31	37
Lagoons (Facultative)	7	8	2	2	10	12
High Purity Oxygen	44	53	N/A	N/A	44(1)	53(1)
Statewide Total	**$135**	**$187**	**$108**	**$152**	**$230**	**$338**
Dry-Season-Only Nutrient Removal						
Extended Aeration (Mechanical Aeration)	9	12	6	9	15	21
Extended Aeration (Diffused Aeration)	0	0	0	1	1	1
Extended Aeration (with Biological Nutrient Removal)	0	0	10	19	11	28
Conventional Activated Sludge	17	24	41	49	54	72
Sequencing Batch Reactor	0	8	1	2	1	9
Trickling Filter	3	4	4	4	7	8
Rotating Biological Contactor	3	4	3	3	6	8
Trickling Filter/Solids Contact	1	2	4	5	5	7
Membrane Bioreactor	0	0	1	1	1	1
Lagoons (Aerated)	24	28	10	12	31	37
Lagoons (Facultative)	7	8	2	2	9	10
High Purity Oxygen	27	32	N/A	N/A	27	32
Statewide Total	**$90**	**$121**	**$81**	**$107**	**$166**	**$236**

Note: (1) costs are for nitrogen removal only

TABLE 17-3.
ESTIMATED ANNUAL CAPITAL AND O&M COSTS FOR NUTRIENT REMOVAL UPGRADES OF ALL TREATMENT PLANTS IN WASHINGTON

	Obj. A	Obj. B	Obj. C	Obj. D	Obj. E	Obj. F
Effluent TIN Limit (mg/L):	<8	<3	—	—	<8	<3
Effluent TP Limit (mg/L):	—	—	<1	<0.1	<1	<0.1
Existing Plant Type	Estimated Annual Cost ($ millions, 2010)[1]					
Year-Round Nutrient Removal						
Extended Aeration (Mechanical Aeration)	14	29	11	23	31	50
Extended Aeration (Diffused Aeration)	0	0	1	1	1	2
Extended Aeration (with Biological Nutrient Removal)	2	9	21	55	17	66
Conventional Activated Sludge	154	176	64	106	206	273
Sequencing Batch Reactor	1	11	2	7	1	17
Trickling Filter	17	20	6	10	22	29
Rotating Biological Contactor	14	16	4	8	18	24
Trickling Filter/Solids Contact	17	19	7	11	22	29
Membrane Bioreactor	0	0	2	2	2	2
Lagoons (Aerated)	75	81	21	27	87	100
Lagoons (Facultative)	19	21	5	7	22	26
High Purity Oxygen	108	129	N/A	N/A	108[2]	129[2]
Statewide Total	**$421**	**$513**	**$143**	**$256**	**$537**	**$748**
Dry-Season-Only Nutrient Removal						
Extended Aeration (Mechanical Aeration)	21	27	8	14	30	42
Extended Aeration (Diffused Aeration)	0	0	1	1	1	2
Extended Aeration (with Biological Nutrient Removal)	3	5	15	36	15	47
Conventional Activated Sludge	55	66	53	78	98	141
Sequencing Batch Reactor	0	10	2	5	2	14
Trickling Filter	9	11	5	7	13	18
Rotating Biological Contactor	8	9	4	6	12	15
Trickling Filter/Solids Contact	7	8	5	8	10	15
Membrane Bioreactor	0	0	2	2	2	2
Lagoons (Aerated)	75	81	21	27	87	100
Lagoons (Facultative)	18	19	4	6	21	23
High Purity Oxygen	51	64	N/A	N/A	51[2]	64[2]
Statewide Total	**$248**	**$300**	**$120**	**$190**	**$344**	**$483**

Notes: [1] Capital cost were annualized for 20 years at 3% discount rate
[2] Cost is for nitrogen removal only

TABLE 17-4.
ESTIMATED MONTHLY HOUSEHOLD SEWER RATE INCREASE FOR NUTRIENT REMOVAL UPGRADES OF ALL TREATMENT PLANTS IN WASHINGTON

	Obj. A	Obj. B	Obj. C	Obj. D	Obj. E	Obj. F
Effluent TIN Limit (mg/L):	<8	<3	—	—	<8	<3
Effluent TP Limit (mg/L):	—	—	<1	<0.1	<1	<0.1
Existing Plant Type	Estimated Monthly Household Sewer Rate Increase [1]					
Year-Round Nutrient Removal						
Extended Aeration (Mechanical Aeration)	$11.29	$24.30	$9.26	$18.96	$25.20	$41.13
Extended Aeration (Diffused Aeration)	$4.09	$7.01	$9.91	$22.18	$15.29	$36.23
Extended Aeration (with Biological Nutrient Removal)	$0.37	$1.66	$4.07	$10.50	$3.31	$12.68
Conventional Activated Sludge	$17.48	$19.95	$7.25	$12.03	$23.33	$30.97
Sequencing Batch Reactor	$1.16	$22.37	$4.71	$13.09	$2.45	$33.21
Trickling Filter	$27.43	$31.48	$8.85	$15.26	$35.23	$46.42
Rotating Biological Contactor	$29.77	$34.14	$9.24	$15.92	$38.27	$49.99
Trickling Filter/Solids Contact	$17.79	$20.08	$6.86	$11.38	$22.33	$30.00
Membrane Bioreactor	$0.00	$0.81	$9.46	$10.67	$9.46	$11.46
Lagoons (Aerated)	$57.67	$62.05	$15.87	$20.91	$66.71	$76.37
Lagoons (Facultative)	$66.89	$74.14	$16.43	$23.38	$78.62	$94.66
High Purity Oxygen	$16.24	$19.47	N/A	N/A	16.24	19.47
Weighted Average	**$16.00**	**$19.48**	**$7.29**	**$13.02**	**$20.40**	**$28.43**
Dry-Season-Only Nutrient Removal						
Extended Aeration (Mechanical Aeration)	$17.71	$22.12	$6.25	$11.73	$24.88	$34.67
Extended Aeration (Diffused Aeration)	$2.34	$4.73	$8.45	$14.66	$15.55	$28.56
Extended Aeration (with Biological Nutrient Removal)	$0.48	$0.98	$2.96	$6.98	$2.97	$8.99
Conventional Activated Sludge	$6.23	$7.46	$6.01	$8.78	$11.15	$16.02
Sequencing Batch Reactor	$0.83	$18.88	$4.54	$10.35	$4.68	$27.51
Trickling Filter	$14.74	$17.01	$7.69	$11.32	$21.47	$28.34
Rotating Biological Contactor	$16.93	$19.46	$8.06	$11.80	$24.21	$31.42
Trickling Filter/Solids Contact	$7.20	$8.19	$5.66	$8.37	$10.84	$15.53
Membrane Bioreactor	$0.00	$0.66	$8.60	$8.77	$8.60	$9.39
Lagoons (Aerated)	$57.67	$62.05	$15.87	$20.91	$66.71	$76.37
Lagoons (Facultative)	$64.37	$68.74	$14.66	$19.74	$73.51	$83.15
High Purity Oxygen	$7.68	$9.70	N/A	N/A	$7.69[2]	$9.70[2]
Weighted Average	**$9.43**	**$11.41**	**$6.08**	**$9.64**	**$13.05**	**$23.28**

Assumptions:
- Maximum-month wastewater flow per capita = 160 gallons
- Population served by treatment plants = 5,484,396
- 2.5 persons per household
- Existing households = 75% of households at design capacity

Notes [1] Capital cost were annualized for 20 years at 3% discount rate
[2] Cost is for nitrogen removal only

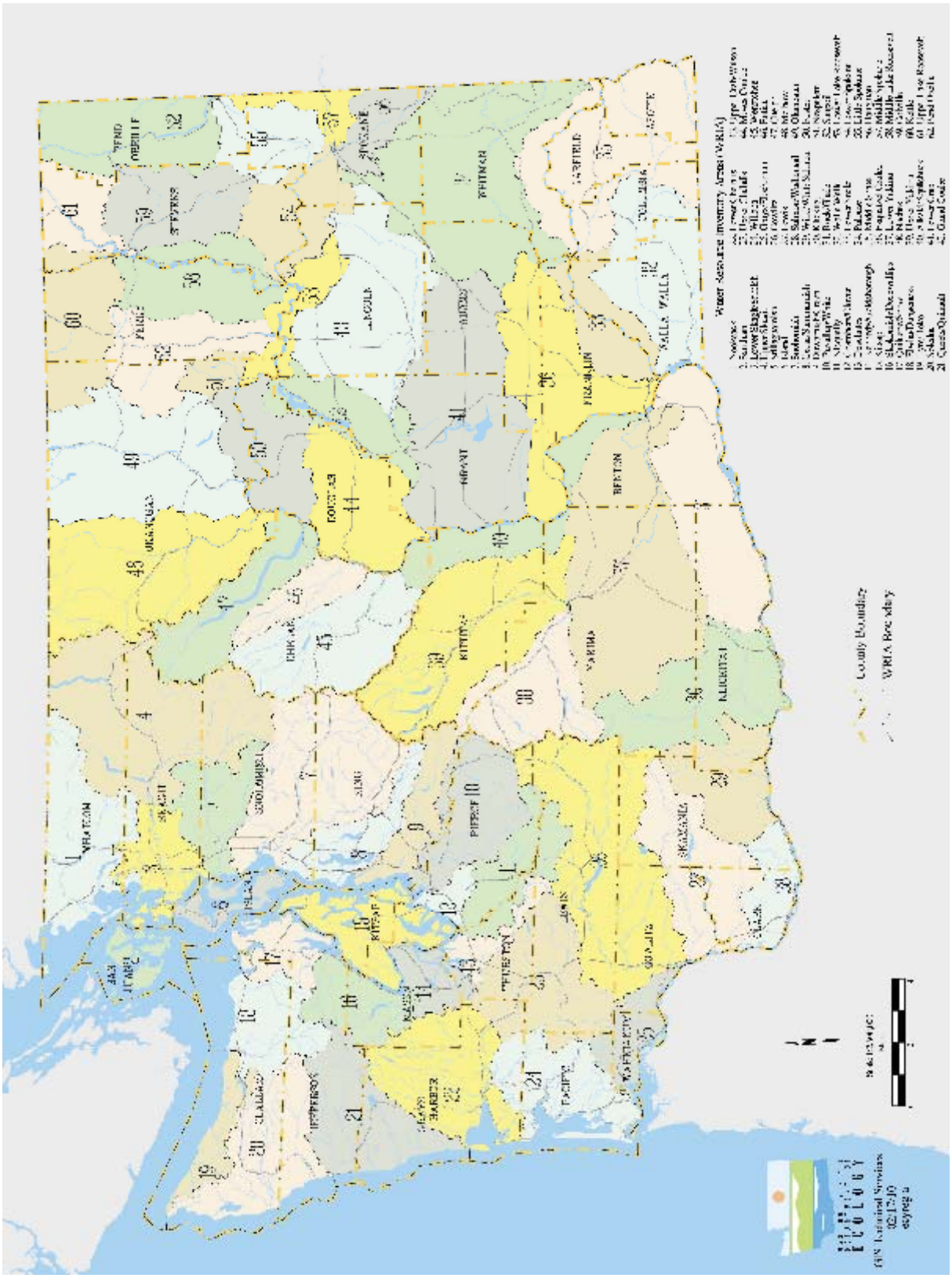

Figure 17-1. Water Resource Inventory Areas in Washington

TABLE 17-5.
ESTIMATED CAPITAL AND O&M COSTS BY WRIA FOR YEAR-ROUND NUTRIENT REMOVAL

	Cost ($ millions, 2010)											
	Objective A		Objective B		Objective C		Objective D		Objective E		Objective F	
	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M
WRIA 1	236.4	7.1	260.5	9.8	28.1	3.4	61.1	4.6	248.8	10.9	306.5	14.4
WRIA 2	6.9	0.3	8.6	0.8	2.4	0.2	5.3	0.3	8.2	0.5	12.6	1.1
WRIA 3	63.2	1.7	76.8	2.9	14.1	3.7	53.0	5.5	72.0	5.2	123.2	8.7
WRIA 4	127.7	3.4	155.3	5.8	29.0	7.6	107.4	11.2	146.2	10.6	249.5	17.6
WRIA 5	10.5	0.2	13.5	1.3	2.9	0.4	9.5	0.7	12.2	0.8	21.7	2.0
WRIA 6	42.2	1.6	46.7	2.6	10.0	0.6	17.5	0.8	46.5	2.5	58.5	3.5
WRIA 7	365.7	7.3	388.2	11.0	54.0	8.6	129.0	11.2	383.8	15.7	482.9	21.7
WRIA 8	1235.6	45.4	1408.5	54.6	40.4	19.8	167.5	25.0	1253.4	61.1	1538.3	78.0
WRIA 9	227.8	6.7	249.7	8.4	19.2	6.2	74.0	7.7	238.4	12.6	313.5	16.5
WRIA 10	481.5	17.1	548.3	21.2	29.0	10.1	111.0	13.4	495.8	25.7	638.6	35.1
WRIA 11	7.3	0.3	9.9	1.2	2.7	0.3	7.1	0.4	9.1	0.5	16.0	1.5
WRIA 12	117.6	3.2	127.6	4.0	9.5	4.0	38.3	5.0	124.1	6.4	160.1	8.7
WRIA 13	0.3	0.0	22.6	0.6	14.2	3.1	43.2	5.1	20.9	2.3	58.2	6.1
WRIA 14	14.8	0.0	18.2	1.2	3.2	0.8	11.3	1.1	16.8	1.1	28.4	2.3
WRIA 15	98.7	2.9	112.2	4.2	14.3	3.9	47.7	5.0	110.8	6.6	155.9	9.2
WRIA 17	12.1	0.2	14.3	0.7	1.9	0.5	7.4	0.7	13.6	0.9	21.2	1.4
WRIA 18	39.8	0.9	44.6	1.6	4.2	1.2	15.8	1.6	42.1	2.1	58.3	3.0
WRIA 19	5.5	0.3	6.1	0.4	0.9	0.1	1.9	0.1	6.2	0.4	7.6	0.4
WRIA 20	15.0	0.6	15.7	0.7	2.9	0.2	4.1	0.3	16.3	0.8	18.0	0.9
WRIA 21	1.6	0.0	1.9	0.2	0.6	0.1	1.5	0.1	2.1	0.2	3.3	0.3
WRIA 22	78.1	1.6	89.6	3.8	9.7	2.9	38.9	4.0	85.6	5.0	125.3	7.7
WRIA 23	5.1	0.0	15.8	1.7	11.3	2.0	43.6	3.9	9.8	2.1	52.6	6.1
WRIA 24	42.8	1.9	47.0	2.8	10.0	0.7	18.4	0.9	47.3	2.6	59.9	3.8
WRIA 25	39.2	1.6	42.1	1.9	9.2	0.4	14.2	0.5	42.4	2.2	50.4	2.7
WRIA 26	14.6	0.5	16.1	1.4	4.3	0.7	9.4	0.9	18.0	1.4	24.5	1.9
WRIA 27	4.6	0.2	8.3	1.2	3.2	0.3	11.0	0.7	6.6	0.5	18.2	1.9
WRIA 28	9.4	0.0	45.2	0.5	29.3	6.8	105.7	11.6	34.8	5.8	131.9	13.9
WRIA 29	5.7	0.0	6.8	0.5	0.9	0.2	4.0	0.4	6.2	0.5	10.5	0.8
WRIA 30	45.4	1.4	47.2	1.7	9.6	0.6	14.0	0.7	49.5	1.9	55.5	2.3
WRIA 31	100.3	1.8	101.9	2.3	22.5	0.9	33.9	1.2	107.8	2.9	122.4	3.7
WRIA 32	10.3	0.0	17.9	0.9	8.7	1.8	31.5	3.0	14.3	2.0	44.5	4.6
WRIA 34	143.2	5.2	158.8	6.8	34.8	2.6	65.4	3.6	156.9	8.5	202.9	11.3
WRIA 35	15.9	0.6	18.2	0.9	2.1	0.5	7.2	0.6	17.8	1.0	24.9	1.4

TABLE 17-5 (continued).
ESTIMATED CAPITAL AND O&M COSTS BY WRIA FOR YEAR-ROUND NUTRIENT REMOVAL

	Cost ($ millions, 2010)											
	Objective A		Objective B		Objective C		Objective D		Objective E		Objective F	
	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M
WRIA 36	48.5	2.0	52.5	2.3	7.5	1.2	16.3	1.4	53.2	2.8	65.0	3.5
WRIA 37	197.5	5.9	217.8	8.1	22.5	5.8	72.9	7.4	213.1	10.9	280.5	15.0
WRIA 38	13.2	0.4	15.3	0.8	1.9	0.5	6.6	0.6	14.9	0.9	21.5	1.3
WRIA 39	49.6	1.6	57.0	2.9	7.4	1.5	24.7	2.2	54.7	2.8	78.3	4.9
WRIA 40	53.8	1.6	59.6	2.0	5.1	1.8	19.9	2.3	58.0	3.1	77.5	4.2
WRIA 41	83.5	2.5	89.3	3.1	17.9	1.6	34.7	2.0	91.7	4.0	114.3	5.4
WRIA 42	11.8	0.6	12.6	0.7	2.4	0.2	3.7	0.3	13.0	0.7	14.8	0.9
WRIA 43	36.5	1.5	40.3	1.8	4.9	1.0	13.0	1.3	40.0	2.2	51.1	2.8
WRIA 44	21.9	0.7	24.8	1.1	2.5	0.7	9.2	0.9	24.1	1.4	33.3	1.8
WRIA 45	55.1	1.7	60.5	2.6	9.4	1.5	21.8	1.9	61.2	3.2	78.3	4.3
WRIA 47	13.3	0.5	14.9	0.6	1.3	0.3	4.9	0.4	14.4	0.8	19.5	1.1
WRIA 48	11.1	0.4	12.5	0.7	1.9	0.3	4.9	0.4	12.4	0.7	16.5	1.0
WRIA 49	19.4	0.4	22.7	1.2	2.8	0.7	11.1	1.0	21.5	1.5	33.0	2.1
WRIA 50	10.1	0.4	10.6	0.5	2.0	0.2	2.9	0.2	11.0	0.5	12.3	0.6
WRIA 52	2.0	0.1	2.2	0.1	0.4	0.0	0.5	0.0	2.2	0.1	2.4	0.2
WRIA 53	2.6	0.2	2.8	0.2	0.5	0.1	0.6	0.1	2.9	0.2	3.1	0.2
WRIA 54	29.4	0.0	45.4	0.0	0.2	0.0	63.1	5.1	38.3	-2.8	114.7	4.5
WRIA 55	3.8	0.3	4.0	0.3	0.7	0.1	0.9	0.1	4.1	0.3	4.5	0.3
WRIA 56	53.7	1.9	57.0	2.7	10.0	1.2	18.5	1.5	58.3	3.0	69.6	3.8
WRIA 60	0.8	0.1	0.9	0.1	0.1	0.0	0.2	0.0	0.9	0.1	1.0	0.1
WRIA 61	2.0	0.1	2.2	0.1	0.4	0.0	0.5	0.0	2.2	0.1	2.4	0.2
WRIA 62	17.4	0.8	20.0	1.0	5.1	0.6	11.0	0.8	19.9	1.3	27.9	1.9

TABLE 17-6.
ESTIMATED CAPITAL AND O&M COSTS BY WRIA FOR DRY-SEASON NUTRIENT REMOVAL

	Cost ($ millions, 2010)											
	Objective A		Objective B		Objective C		Objective D		Objective E		Objective F	
	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M
WRIA 1	160.6	5.7	177.7	7.4	28.3	2.6	51.2	3.4	174.3	8.5	215.5	11.1
WRIA 2	6.6	0.3	8.1	0.7	2.4	0.2	4.3	0.3	8.3	0.5	11.6	1.0
WRIA 3	27.5	1.3	35.5	1.8	15.2	2.7	38.7	3.7	38.0	3.9	70.0	5.9
WRIA 4	55.3	2.6	71.5	3.6	31.2	5.4	78.4	7.4	77.1	7.9	141.7	12.0
WRIA 5	10.1	0.5	12.6	1.2	2.8	0.3	7.3	0.5	12.3	0.8	19.2	1.6
WRIA 6	38.1	1.7	40.4	2.3	9.0	0.5	13.6	0.7	42.4	2.2	49.5	2.9
WRIA 7	253.6	5.1	264.8	7.0	58.9	6.6	108.7	8.3	273.2	11.4	343.8	15.4
WRIA 8	477.6	22.8	564.0	28.2	59.6	13.7	139.6	16.6	497.7	35.1	694.0	44.5
WRIA 9	113.5	3.2	124.1	4.2	23.7	4.8	54.6	5.7	122.0	8.4	169.0	10.8
WRIA 10	182.2	8.3	220.7	10.9	37.2	7.3	86.8	9.2	200.1	15.5	299.1	21.1
WRIA 11	5.1	0.3	7.3	1.0	2.7	0.3	5.9	0.4	6.9	0.5	12.3	1.3
WRIA 12	41.1	1.0	45.3	1.4	13.1	2.9	30.3	3.5	47.6	3.7	73.8	5.0
WRIA 13	0.3	0.0	5.0	0.6	14.3	2.0	35.6	3.1	8.0	1.8	33.3	4.0
WRIA 14	13.5	0.4	16.1	1.1	3.1	0.5	8.0	0.7	16.6	1.0	24.1	1.9
WRIA 15	35.0	1.7	42.8	2.3	15.8	3.1	33.7	3.7	47.1	4.6	75.2	6.2
WRIA 17	8.6	0.4	10.1	0.6	1.9	0.4	4.8	0.5	10.6	0.8	15.1	1.2
WRIA 18	19.0	0.5	21.6	0.8	5.0	0.9	11.3	1.2	21.3	1.4	31.2	2.0
WRIA 19	4.5	0.3	5.0	0.4	0.9	0.1	1.5	0.1	5.1	0.4	6.1	0.4
WRIA 20	15.0	0.6	15.7	0.7	2.9	0.2	4.1	0.3	16.3	0.8	18.0	0.9
WRIA 21	1.4	0.2	1.7	0.2	0.6	0.1	1.0	0.1	2.1	0.2	2.8	0.2
WRIA 22	40.9	1.5	48.0	2.6	10.6	2.2	27.2	2.8	49.8	3.8	74.7	5.5
WRIA 23	4.6	0.3	12.4	1.3	11.3	1.4	32.7	2.4	12.3	1.7	40.7	4.3
WRIA 24	37.6	1.8	40.6	2.6	9.2	0.6	14.8	0.8	42.1	2.4	50.5	3.3
WRIA 25	37.8	1.5	38.9	1.7	8.1	0.4	11.6	0.5	40.9	1.9	45.6	2.2
WRIA 26	12.4	1.1	14.0	1.2	4.2	0.6	6.7	0.7	16.5	1.5	20.4	1.8
WRIA 27	1.8	0.1	4.9	1.0	3.1	0.3	8.3	0.5	4.2	0.4	12.5	1.5
WRIA 28	8.1	0.3	20.9	0.5	29.8	4.2	81.3	6.9	25.6	4.6	87.6	9.1
WRIA 29	5.2	0.4	6.0	0.5	0.9	0.2	2.4	0.2	6.4	0.5	8.8	0.7
WRIA 30	44.7	1.4	46.5	1.7	9.6	0.6	13.8	0.7	48.8	1.9	54.5	2.3
WRIA 31	98.3	1.8	99.8	2.3	22.5	0.9	33.3	1.2	105.8	2.9	119.6	3.7
WRIA 32	9.8	0.3	15.2	0.8	8.8	1.2	22.8	1.9	16.8	1.7	35.6	3.4
WRIA 34	132.7	5.3	139.9	6.2	31.0	2.2	50.7	2.8	147.4	7.4	174.4	9.3
WRIA 35	6.4	0.5	7.8	0.6	2.3	0.4	4.9	0.5	8.1	0.8	12.3	1.0

TABLE 17-6 (continued).
ESTIMATED CAPITAL AND O&M COSTS BY WRIA FOR DRY-SEASON NUTRIENT REMOVAL

	Cost ($ millions, 2010)											
	Objective A		Objective B		Objective C		Objective D		Objective E		Objective F	
	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M
WRIA 36	33.8	1.6	36.8	1.9	8.0	1.1	13.6	1.2	38.2	2.4	46.8	2.9
WRIA 37	92.2	3.3	103.6	4.6	26.3	4.6	56.0	5.5	106.8	7.5	152.6	10.1
WRIA 38	5.0	0.4	6.3	0.5	2.1	0.4	4.4	0.4	6.7	0.7	10.6	1.0
WRIA 39	23.5	0.9	28.4	1.9	8.3	1.3	19.5	1.6	28.3	2.0	45.4	3.4
WRIA 40	18.1	0.6	21.0	0.9	6.5	1.4	14.9	1.7	22.1	1.9	35.1	2.6
WRIA 41	70.3	2.3	75.0	2.8	18.0	1.4	29.2	1.8	79.2	3.7	95.3	4.8
WRIA 42	11.6	0.6	12.4	0.7	2.4	0.2	3.4	0.3	12.9	0.8	14.5	0.9
WRIA 43	20.4	1.1	22.8	1.3	5.4	0.9	10.2	1.0	23.7	1.7	31.2	2.2
WRIA 44	7.9	0.5	9.6	0.6	2.9	0.6	6.5	0.7	10.0	1.0	15.7	1.3
WRIA 45	35.8	1.4	39.4	1.9	10.0	1.3	17.6	1.5	42.1	2.6	53.8	3.4
WRIA 47	7.2	0.3	8.1	0.4	1.5	0.3	3.3	0.3	8.1	0.6	11.0	0.8
WRIA 48	8.8	0.5	9.8	0.6	1.9	0.3	3.6	0.3	10.2	0.7	12.8	0.9
WRIA 49	13.9	0.8	16.2	1.1	2.7	0.5	6.9	0.7	16.8	1.3	23.2	1.8
WRIA 50	10.1	0.5	10.6	0.5	2.0	0.2	2.9	0.2	11.0	0.5	12.2	0.6
WRIA 52	2.0	0.1	2.2	0.1	0.4	0.0	0.5	0.0	2.2	0.1	2.4	0.2
WRIA 53	2.6	0.2	2.8	0.2	0.5	0.1	0.6	0.1	2.9	0.2	3.1	0.2
WRIA 54	38.0	0.0	41.8	0.0	0.2	0.0	51.3	2.7	19.1	0.1	72.7	6.4
WRIA 55	3.8	0.3	4.0	0.3	0.7	0.1	0.9	0.1	4.1	0.3	4.5	0.3
WRIA 56	52.8	2.2	56.0	2.6	9.9	1.0	16.2	1.2	58.3	3.0	67.0	3.6
WRIA 60	0.8	0.1	0.9	0.1	0.1	0.0	0.2	0.0	0.9	0.1	1.0	0.1
WRIA 61	2.0	0.1	2.2	0.1	0.4	0.0	0.5	0.0	2.2	0.1	2.4	0.2
WRIA 62	16.9	0.9	19.1	1.0	5.1	0.5	8.7	0.7	20.3	1.3	25.6	1.7

17.4 CONCLUSIONS

17.4.1 Nitrogen Removal

For nitrogen removal, seasonal operation is slightly more cost-effective (per pound of nitrogen removed) than year-round operation. Year-round removal requires significantly more capital investment to upgrade treatment facilities. However, seasonal removal generally would provide only about 60 percent of the nitrogen removal provided by year-round removal, on an annual mass basis.

Implementing nitrogen removal generally would slightly reduce the amount of sludge produced at a treatment plant (up to 3 percent). Reducing nitrogen to 3 mg/L, however, generally requires the addition of a carbon substrate, which would produce additional sludge—up to 5 percent above existing rates.

Energy consumption for nitrogen removal would be significant. Reducing the TIN effluent concentration statewide to less than 8 mg/L would require approximately two to three times the amount of electrical energy currently used by municipal wastewater treatment facilities. Moreover, existing energy recovery processes at treatment facilities that rely on the production of methane gas from sludge would produce approximately 5 to 10 percent less energy as a consequence of the removal of nitrogen.

17.4.2 Phosphorus Removal

For phosphorus removal, seasonal removal is generally less cost-effective (per pound of phosphorus removed) than year-round removal. Both approaches require about the same capital investment to upgrade treatment facilities, but seasonal removal generally would provide only about 60 percent of the phosphorus removal provided by year-round removal, on an annual mass basis.

Phosphorus removal by chemical precipitation produces significantly more sludge than existing processes—approximately 25 to 35 percent more.

Energy consumption would increase for phosphorus removal, but significantly less than for nitrogen removal. Reducing the TP effluent concentration statewide to less than 1 mg/L would increase treatment plant electrical energy consumption by approximately 15 to 20 percent.

CHAPTER 17.
CUMULATIVE COST IMPACT SUMMARY

17.1 CUMULATIVE STATEWIDE COST

Cost models presented in previous chapters of this report represent expected costs for upgrading individual treatment plants to meet a range of potential objectives for limiting nitrogen and phosphorus in effluent discharged to surface waters. If the State of Washington were to adopt regulatory guidelines establishing such limits, then municipal treatment plants throughout the state would need to perform upgrades, with potentially significant statewide cost implications.

In order to assess the magnitude of such potential future cost impacts, the cost models developed for each of the respective nutrient removal objectives (i.e., Chapters 11-16) were applied to Ecology's list of all municipal treatment plants operating in Washington. As described in Chapter 2, there are currently 304 such plants operating in the state. Using a list of the treatment type and maximum-month capacity for each of these plants, the upgrade capital and O&M cost models identified in the previous chapters for several capacities for each type of plant were used to estimate upgrade costs for each specific plant operating in the state. These costs were then totaled by treatment type and on a statewide basis. Tables 17-1, 17-2 and 17-3 present the results for capital cost, annual O&M cost and 20-year annualized total cost (assuming a 3-percent discount rate), respectively. The expected accuracy range for these estimates is +100% to -50% percent. Actual costs for a specific facility would have to be determined through a site specific engineering study.

17.2 POTENTIAL SEWER RATE IMPACTS

Based on the cumulate statewide costs estimated as described above, an evaluation was performed to estimate the likely cost impact on sewer rates per household. The monthly increase was calculated from the annualized statewide costs, assuming a statewide population of about 5.5 million, an average household size of 2.5 persons, a per capita maximum-month wastewater flow of 160 gallons, and a future number of households at design capacity equal to 1.33 times the current number of households. The resulting rate impact estimates are shown in Table 17-4.

17.3 WATERSHED-WIDE COSTS FOR NUTRIENT REMOVAL

For planning purposes, the Washington Department of Ecology has divided the state into 62 Water Resource Inventory Areas (WRIAs), representing the watershed, or drainage area, of all major water bodies in the state (see Figure 17-1). Water quality assessments and measures to address water quality problems often are developed based on these watershed designations, because the WRIAs represent all the area potentially contributing nutrients and other contaminants to affected water bodies. Therefore, if a given water body is experiencing water quality problems related to high levels of nitrogen or phosphorus, then nutrient discharge limits might be established that apply to all dischargers within that water body's WRIA. For this reason, it is useful to estimate the potential cost of upgrading all municipal treatment plants in each WRIA to achieve the various nutrient removal objectives. These estimates were made using the same approach described above for the statewide cost estimates. Tables 17-5 and 17-6 present the results for capital cost and annual O&M cost. Additional detail on costs in each WRIA is provided in Appendix D. The expected accuracy range for these estimates is +100% to -50% percent. Actual costs for a specific facility would have to be determined through a site specific engineering study.

TABLE 17-1.
ESTIMATED CAPITAL COSTS FOR NUTRIENT REMOVAL UPGRADES OF ALL TREATMENT PLANTS IN WASHINGTON

	Obj. A	Obj. B	Obj. C	Obj. D	Obj. E	Obj. F
Effluent TIN Limit (mg/L):	<8	<3	—	—	<8	<3
Effluent TP Limit (mg/L):	—	—	<1	<0.1	<1	<0.1
Existing Plant Type	Estimated Capital Cost ($ millions, 2010)					
Year-Round Nutrient Removal						
Extended Aeration (Mechanical Aeration)	204	239	29	133	221	360
Extended Aeration (Diffused Aeration)	4	7	3	11	5	16
Extended Aeration (with Biological Nutrient Removal)	29	128	75	328	94	414
Conventional Activated Sludge	1625	1773	142	559	1725	2253
Sequencing Batch Reactor	7	28	18	54	18	76
Trickling Filter	177	195	15	58	186	246
Rotating Biological Contactor	140	155	13	47	148	197
Trickling Filter/Solids Contact	193	207	15	59	193	252
Membrane Bioreactor	0	0	11	10	11	11
Lagoons (Aerated)	773	797	163	234	836	931
Lagoons (Facultative)	170	182	40	62	184	218
High Purity Oxygen	942	1134	N/A	N/A	942(1)	1134(1)
Statewide Total	**$4,264**	**$4,844**	**$522**	**$1,555**	**$4,564**	**$6,107**
Dry-Season-Only Nutrient Removal						
Extended Aeration (Mechanical Aeration)	192	217	28	84	227	308
Extended Aeration (Diffused Aeration)	2	5	3	7	6	11
Extended Aeration (with Biological Nutrient Removal)	38	76	76	252	66	272
Conventional Activated Sludge	564	629	185	429	660	1032
Sequencing Batch Reactor	6	25	18	46	18	66
Trickling Filter	96	105	18	42	102	138
Rotating Biological Contactor	76	84	15	33	82	111
Trickling Filter/Solids Contact	88	93	20	46	88	127
Membrane Bioreactor	0	0	10	10	10	10
Lagoons (Aerated)	773	797	163	234	836	931
Lagoons (Facultative)	164	168	35	50	177	197
High Purity Oxygen	363	477	N/A	N/A	363(1)	477(1)
Statewide Total	**$2,360**	**$2,674**	**$570**	**$1,233**	**$2,635**	**$3,680**

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Note: (1) costs are for nitrogen removal only

TABLE 17-2.
ESTIMATED ANNUAL O&M COSTS FOR NUTRIENT REMOVAL UPGRADES OF ALL TREATMENT PLANTS IN WASHINGTON

	Obj. A	Obj. B	Obj. C	Obj. D	Obj. E	Obj. F
Effluent TIN Limit (mg/L):	<8	<3	—	—	<8	<3
Effluent TP Limit (mg/L):	—	—	<1	<0.1	<1	<0.1
Existing Plant Type	Estimated Annual O&M Cost ($ millions, 2010)					
Year-Round Nutrient Removal						
Extended Aeration (Mechanical Aeration)	0	13	9	14	16	26
Extended Aeration (Diffused Aeration)	0	0	0	1	1	1
Extended Aeration (with Biological Nutrient Removal)	0	0	16	33	11	38
Conventional Activated Sludge	45	57	55	69	90	122
Sequencing Batch Reactor	0	9	1	3	0	12
Trickling Filter	5	7	4	6	9	12
Rotating Biological Contactor	5	6	4	4	8	11
Trickling Filter/Solids Contact	4	6	6	7	9	12
Membrane Bioreactor	0	0	1	2	1	2
Lagoons (Aerated)	24	28	10	12	31	37
Lagoons (Facultative)	7	8	2	2	10	12
High Purity Oxygen	44	53	N/A	N/A	44(1)	53(1)
Statewide Total	**$135**	**$187**	**$108**	**$152**	**$230**	**$338**
Dry-Season-Only Nutrient Removal						
Extended Aeration (Mechanical Aeration)	9	12	6	9	15	21
Extended Aeration (Diffused Aeration)	0	0	0	1	1	1
Extended Aeration (with Biological Nutrient Removal)	0	0	10	19	11	28
Conventional Activated Sludge	17	24	41	49	54	72
Sequencing Batch Reactor	0	8	1	2	1	9
Trickling Filter	3	4	4	4	7	8
Rotating Biological Contactor	3	4	3	3	6	8
Trickling Filter/Solids Contact	1	2	4	5	5	7
Membrane Bioreactor	0	0	1	1	1	1
Lagoons (Aerated)	24	28	10	12	31	37
Lagoons (Facultative)	7	8	2	2	9	10
High Purity Oxygen	27	32	N/A	N/A	27	32
Statewide Total	**$90**	**$121**	**$81**	**$107**	**$166**	**$236**

Note: (1) costs are for nitrogen removal only

TABLE 17-3.
ESTIMATED ANNUAL CAPITAL AND O&M COSTS FOR NUTRIENT REMOVAL UPGRADES OF ALL TREATMENT PLANTS IN WASHINGTON

	Obj. A	Obj. B	Obj. C	Obj. D	Obj. E	Obj. F
Effluent TIN Limit (mg/L):	<8	<3	—	—	<8	<3
Effluent TP Limit (mg/L):	—	—	<1	<0.1	<1	<0.1
Existing Plant Type	Estimated Annual Cost ($ millions, 2010)[1]					
Year-Round Nutrient Removal						
Extended Aeration (Mechanical Aeration)	14	29	11	23	31	50
Extended Aeration (Diffused Aeration)	0	0	1	1	1	2
Extended Aeration (with Biological Nutrient Removal)	2	9	21	55	17	66
Conventional Activated Sludge	154	176	64	106	206	273
Sequencing Batch Reactor	1	11	2	7	1	17
Trickling Filter	17	20	6	10	22	29
Rotating Biological Contactor	14	16	4	8	18	24
Trickling Filter/Solids Contact	17	19	7	11	22	29
Membrane Bioreactor	0	0	2	2	2	2
Lagoons (Aerated)	75	81	21	27	87	100
Lagoons (Facultative)	19	21	5	7	22	26
High Purity Oxygen	108	129	N/A	N/A	108[2]	129[2]
Statewide Total	**$421**	**$513**	**$143**	**$256**	**$537**	**$748**
Dry-Season-Only Nutrient Removal						
Extended Aeration (Mechanical Aeration)	21	27	8	14	30	42
Extended Aeration (Diffused Aeration)	0	0	1	1	1	2
Extended Aeration (with Biological Nutrient Removal)	3	5	15	36	15	47
Conventional Activated Sludge	55	66	53	78	98	141
Sequencing Batch Reactor	0	10	2	5	2	14
Trickling Filter	9	11	5	7	13	18
Rotating Biological Contactor	8	9	4	6	12	15
Trickling Filter/Solids Contact	7	8	5	8	10	15
Membrane Bioreactor	0	0	2	2	2	2
Lagoons (Aerated)	75	81	21	27	87	100
Lagoons (Facultative)	18	19	4	6	21	23
High Purity Oxygen	51	64	N/A	N/A	51[2]	64[2]
Statewide Total	**$248**	**$300**	**$120**	**$190**	**$344**	**$483**

Notes: [1] Capital cost were annualized for 20 years at 3% discount rate
[2] Cost is for nitrogen removal only

TABLE 17-4.
ESTIMATED MONTHLY HOUSEHOLD SEWER RATE INCREASE FOR NUTRIENT REMOVAL UPGRADES OF ALL TREATMENT PLANTS IN WASHINGTON

	Obj. A	Obj. B	Obj. C	Obj. D	Obj. E	Obj. F
Effluent TIN Limit (mg/L):	<8	<3	—	—	<8	<3
Effluent TP Limit (mg/L):	—	—	<1	<0.1	<1	<0.1
Existing Plant Type	Estimated Monthly Household Sewer Rate Increase [1]					
Year-Round Nutrient Removal						
Extended Aeration (Mechanical Aeration)	$11.29	$24.30	$9.26	$18.96	$25.20	$41.13
Extended Aeration (Diffused Aeration)	$4.09	$7.01	$9.91	$22.18	$15.29	$36.23
Extended Aeration (with Biological Nutrient Removal)	$0.37	$1.66	$4.07	$10.50	$3.31	$12.68
Conventional Activated Sludge	$17.48	$19.95	$7.25	$12.03	$23.33	$30.97
Sequencing Batch Reactor	$1.16	$22.37	$4.71	$13.09	$2.45	$33.21
Trickling Filter	$27.43	$31.48	$8.85	$15.26	$35.23	$46.42
Rotating Biological Contactor	$29.77	$34.14	$9.24	$15.92	$38.27	$49.99
Trickling Filter/Solids Contact	$17.79	$20.08	$6.86	$11.38	$22.33	$30.00
Membrane Bioreactor	$0.00	$0.81	$9.46	$10.67	$9.46	$11.46
Lagoons (Aerated)	$57.67	$62.05	$15.87	$20.91	$66.71	$76.37
Lagoons (Facultative)	$66.89	$74.14	$16.43	$23.38	$78.62	$94.66
High Purity Oxygen	$16.24	$19.47	N/A	N/A	16.24	19.47
Weighted Average	**$16.00**	**$19.48**	**$7.29**	**$13.02**	**$20.40**	**$28.43**
Dry-Season-Only Nutrient Removal						
Extended Aeration (Mechanical Aeration)	$17.71	$22.12	$6.25	$11.73	$24.88	$34.67
Extended Aeration (Diffused Aeration)	$2.34	$4.73	$8.45	$14.66	$15.55	$28.56
Extended Aeration (with Biological Nutrient Removal)	$0.48	$0.98	$2.96	$6.98	$2.97	$8.99
Conventional Activated Sludge	$6.23	$7.46	$6.01	$8.78	$11.15	$16.02
Sequencing Batch Reactor	$0.83	$18.88	$4.54	$10.35	$4.68	$27.51
Trickling Filter	$14.74	$17.01	$7.69	$11.32	$21.47	$28.34
Rotating Biological Contactor	$16.93	$19.46	$8.06	$11.80	$24.21	$31.42
Trickling Filter/Solids Contact	$7.20	$8.19	$5.66	$8.37	$10.84	$15.53
Membrane Bioreactor	$0.00	$0.66	$8.60	$8.77	$8.60	$9.39
Lagoons (Aerated)	$57.67	$62.05	$15.87	$20.91	$66.71	$76.37
Lagoons (Facultative)	$64.37	$68.74	$14.66	$19.74	$73.51	$83.15
High Purity Oxygen	$7.68	$9.70	N/A	N/A	$7.69[2]	$9.70[2]
Weighted Average	**$9.43**	**$11.41**	**$6.08**	**$9.64**	**$13.05**	**$23.28**

Assumptions:
- Maximum-month wastewater flow per capita = 160 gallons
- Population served by treatment plants = 5,484,396
- 2.5 persons per household
- Existing households = 75% of households at design capacity

Notes [1] Capital cost were annualized for 20 years at 3% discount rate
[2] Cost is for nitrogen removal only

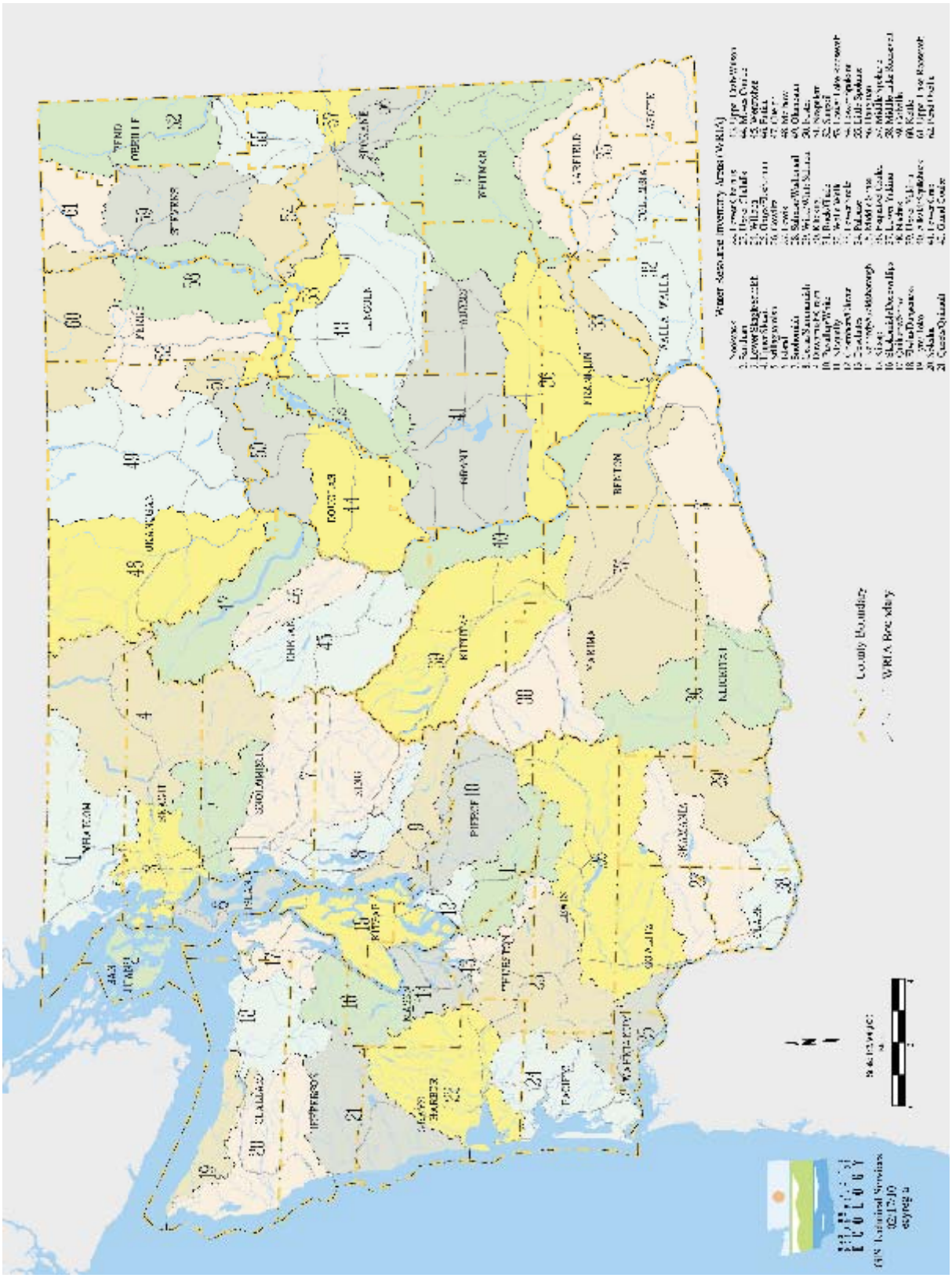

Figure 17-1. Water Resource Inventory Areas in Washington

TABLE 17-5.
ESTIMATED CAPITAL AND O&M COSTS BY WRIA FOR YEAR-ROUND NUTRIENT REMOVAL

	Cost ($ millions, 2010)											
	Objective A		Objective B		Objective C		Objective D		Objective E		Objective F	
	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M
WRIA 1	236.4	7.1	260.5	9.8	28.1	3.4	61.1	4.6	248.8	10.9	306.5	14.4
WRIA 2	6.9	0.3	8.6	0.8	2.4	0.2	5.3	0.3	8.2	0.5	12.6	1.1
WRIA 3	63.2	1.7	76.8	2.9	14.1	3.7	53.0	5.5	72.0	5.2	123.2	8.7
WRIA 4	127.7	3.4	155.3	5.8	29.0	7.6	107.4	11.2	146.2	10.6	249.5	17.6
WRIA 5	10.5	0.2	13.5	1.3	2.9	0.4	9.5	0.7	12.2	0.8	21.7	2.0
WRIA 6	42.2	1.6	46.7	2.6	10.0	0.6	17.5	0.8	46.5	2.5	58.5	3.5
WRIA 7	365.7	7.3	388.2	11.0	54.0	8.6	129.0	11.2	383.8	15.7	482.9	21.7
WRIA 8	1235.6	45.4	1408.5	54.6	40.4	19.8	167.5	25.0	1253.4	61.1	1538.3	78.0
WRIA 9	227.8	6.7	249.7	8.4	19.2	6.2	74.0	7.7	238.4	12.6	313.5	16.5
WRIA 10	481.5	17.1	548.3	21.2	29.0	10.1	111.0	13.4	495.8	25.7	638.6	35.1
WRIA 11	7.3	0.3	9.9	1.2	2.7	0.3	7.1	0.4	9.1	0.5	16.0	1.5
WRIA 12	117.6	3.2	127.6	4.0	9.5	4.0	38.3	5.0	124.1	6.4	160.1	8.7
WRIA 13	0.3	0.0	22.6	0.6	14.2	3.1	43.2	5.1	20.9	2.3	58.2	6.1
WRIA 14	14.8	0.0	18.2	1.2	3.2	0.8	11.3	1.1	16.8	1.1	28.4	2.3
WRIA 15	98.7	2.9	112.2	4.2	14.3	3.9	47.7	5.0	110.8	6.6	155.9	9.2
WRIA 17	12.1	0.2	14.3	0.7	1.9	0.5	7.4	0.7	13.6	0.9	21.2	1.4
WRIA 18	39.8	0.9	44.6	1.6	4.2	1.2	15.8	1.6	42.1	2.1	58.3	3.0
WRIA 19	5.5	0.3	6.1	0.4	0.9	0.1	1.9	0.1	6.2	0.4	7.6	0.4
WRIA 20	15.0	0.6	15.7	0.7	2.9	0.2	4.1	0.3	16.3	0.8	18.0	0.9
WRIA 21	1.6	0.0	1.9	0.2	0.6	0.1	1.5	0.1	2.1	0.2	3.3	0.3
WRIA 22	78.1	1.6	89.6	3.8	9.7	2.9	38.9	4.0	85.6	5.0	125.3	7.7
WRIA 23	5.1	0.0	15.8	1.7	11.3	2.0	43.6	3.9	9.8	2.1	52.6	6.1
WRIA 24	42.8	1.9	47.0	2.8	10.0	0.7	18.4	0.9	47.3	2.6	59.9	3.8
WRIA 25	39.2	1.6	42.1	1.9	9.2	0.4	14.2	0.5	42.4	2.2	50.4	2.7
WRIA 26	14.6	0.5	16.1	1.4	4.3	0.7	9.4	0.9	18.0	1.4	24.5	1.9
WRIA 27	4.6	0.2	8.3	1.2	3.2	0.3	11.0	0.7	6.6	0.5	18.2	1.9
WRIA 28	9.4	0.0	45.2	0.5	29.3	6.8	105.7	11.6	34.8	5.8	131.9	13.9
WRIA 29	5.7	0.0	6.8	0.5	0.9	0.2	4.0	0.4	6.2	0.5	10.5	0.8
WRIA 30	45.4	1.4	47.2	1.7	9.6	0.6	14.0	0.7	49.5	1.9	55.5	2.3
WRIA 31	100.3	1.8	101.9	2.3	22.5	0.9	33.9	1.2	107.8	2.9	122.4	3.7
WRIA 32	10.3	0.0	17.9	0.9	8.7	1.8	31.5	3.0	14.3	2.0	44.5	4.6
WRIA 34	143.2	5.2	158.8	6.8	34.8	2.6	65.4	3.6	156.9	8.5	202.9	11.3
WRIA 35	15.9	0.6	18.2	0.9	2.1	0.5	7.2	0.6	17.8	1.0	24.9	1.4

TABLE 17-5 (continued).
ESTIMATED CAPITAL AND O&M COSTS BY WRIA FOR YEAR-ROUND NUTRIENT REMOVAL

	Cost ($ millions, 2010)											
	Objective A		Objective B		Objective C		Objective D		Objective E		Objective F	
	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M
WRIA 36	48.5	2.0	52.5	2.3	7.5	1.2	16.3	1.4	53.2	2.8	65.0	3.5
WRIA 37	197.5	5.9	217.8	8.1	22.5	5.8	72.9	7.4	213.1	10.9	280.5	15.0
WRIA 38	13.2	0.4	15.3	0.8	1.9	0.5	6.6	0.6	14.9	0.9	21.5	1.3
WRIA 39	49.6	1.6	57.0	2.9	7.4	1.5	24.7	2.2	54.7	2.8	78.3	4.9
WRIA 40	53.8	1.6	59.6	2.0	5.1	1.8	19.9	2.3	58.0	3.1	77.5	4.2
WRIA 41	83.5	2.5	89.3	3.1	17.9	1.6	34.7	2.0	91.7	4.0	114.3	5.4
WRIA 42	11.8	0.6	12.6	0.7	2.4	0.2	3.7	0.3	13.0	0.7	14.8	0.9
WRIA 43	36.5	1.5	40.3	1.8	4.9	1.0	13.0	1.3	40.0	2.2	51.1	2.8
WRIA 44	21.9	0.7	24.8	1.1	2.5	0.7	9.2	0.9	24.1	1.4	33.3	1.8
WRIA 45	55.1	1.7	60.5	2.6	9.4	1.5	21.8	1.9	61.2	3.2	78.3	4.3
WRIA 47	13.3	0.5	14.9	0.6	1.3	0.3	4.9	0.4	14.4	0.8	19.5	1.1
WRIA 48	11.1	0.4	12.5	0.7	1.9	0.3	4.9	0.4	12.4	0.7	16.5	1.0
WRIA 49	19.4	0.4	22.7	1.2	2.8	0.7	11.1	1.0	21.5	1.5	33.0	2.1
WRIA 50	10.1	0.4	10.6	0.5	2.0	0.2	2.9	0.2	11.0	0.5	12.3	0.6
WRIA 52	2.0	0.1	2.2	0.1	0.4	0.0	0.5	0.0	2.2	0.1	2.4	0.2
WRIA 53	2.6	0.2	2.8	0.2	0.5	0.1	0.6	0.1	2.9	0.2	3.1	0.2
WRIA 54	29.4	0.0	45.4	0.0	0.2	0.0	63.1	5.1	38.3	-2.8	114.7	4.5
WRIA 55	3.8	0.3	4.0	0.3	0.7	0.1	0.9	0.1	4.1	0.3	4.5	0.3
WRIA 56	53.7	1.9	57.0	2.7	10.0	1.2	18.5	1.5	58.3	3.0	69.6	3.8
WRIA 60	0.8	0.1	0.9	0.1	0.1	0.0	0.2	0.0	0.9	0.1	1.0	0.1
WRIA 61	2.0	0.1	2.2	0.1	0.4	0.0	0.5	0.0	2.2	0.1	2.4	0.2
WRIA 62	17.4	0.8	20.0	1.0	5.1	0.6	11.0	0.8	19.9	1.3	27.9	1.9

TABLE 17-6.
ESTIMATED CAPITAL AND O&M COSTS BY WRIA FOR DRY-SEASON NUTRIENT REMOVAL

	Cost ($ millions, 2010)											
	Objective A		Objective B		Objective C		Objective D		Objective E		Objective F	
	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M
WRIA 1	160.6	5.7	177.7	7.4	28.3	2.6	51.2	3.4	174.3	8.5	215.5	11.1
WRIA 2	6.6	0.3	8.1	0.7	2.4	0.2	4.3	0.3	8.3	0.5	11.6	1.0
WRIA 3	27.5	1.3	35.5	1.8	15.2	2.7	38.7	3.7	38.0	3.9	70.0	5.9
WRIA 4	55.3	2.6	71.5	3.6	31.2	5.4	78.4	7.4	77.1	7.9	141.7	12.0
WRIA 5	10.1	0.5	12.6	1.2	2.8	0.3	7.3	0.5	12.3	0.8	19.2	1.6
WRIA 6	38.1	1.7	40.4	2.3	9.0	0.5	13.6	0.7	42.4	2.2	49.5	2.9
WRIA 7	253.6	5.1	264.8	7.0	58.9	6.6	108.7	8.3	273.2	11.4	343.8	15.4
WRIA 8	477.6	22.8	564.0	28.2	59.6	13.7	139.6	16.6	497.7	35.1	694.0	44.5
WRIA 9	113.5	3.2	124.1	4.2	23.7	4.8	54.6	5.7	122.0	8.4	169.0	10.8
WRIA 10	182.2	8.3	220.7	10.9	37.2	7.3	86.8	9.2	200.1	15.5	299.1	21.1
WRIA 11	5.1	0.3	7.3	1.0	2.7	0.3	5.9	0.4	6.9	0.5	12.3	1.3
WRIA 12	41.1	1.0	45.3	1.4	13.1	2.9	30.3	3.5	47.6	3.7	73.8	5.0
WRIA 13	0.3	0.0	5.0	0.6	14.3	2.0	35.6	3.1	8.0	1.8	33.3	4.0
WRIA 14	13.5	0.4	16.1	1.1	3.1	0.5	8.0	0.7	16.6	1.0	24.1	1.9
WRIA 15	35.0	1.7	42.8	2.3	15.8	3.1	33.7	3.7	47.1	4.6	75.2	6.2
WRIA 17	8.6	0.4	10.1	0.6	1.9	0.4	4.8	0.5	10.6	0.8	15.1	1.2
WRIA 18	19.0	0.5	21.6	0.8	5.0	0.9	11.3	1.2	21.3	1.4	31.2	2.0
WRIA 19	4.5	0.3	5.0	0.4	0.9	0.1	1.5	0.1	5.1	0.4	6.1	0.4
WRIA 20	15.0	0.6	15.7	0.7	2.9	0.2	4.1	0.3	16.3	0.8	18.0	0.9
WRIA 21	1.4	0.2	1.7	0.2	0.6	0.1	1.0	0.1	2.1	0.2	2.8	0.2
WRIA 22	40.9	1.5	48.0	2.6	10.6	2.2	27.2	2.8	49.8	3.8	74.7	5.5
WRIA 23	4.6	0.3	12.4	1.3	11.3	1.4	32.7	2.4	12.3	1.7	40.7	4.3
WRIA 24	37.6	1.8	40.6	2.6	9.2	0.6	14.8	0.8	42.1	2.4	50.5	3.3
WRIA 25	37.8	1.5	38.9	1.7	8.1	0.4	11.6	0.5	40.9	1.9	45.6	2.2
WRIA 26	12.4	1.1	14.0	1.2	4.2	0.6	6.7	0.7	16.5	1.5	20.4	1.8
WRIA 27	1.8	0.1	4.9	1.0	3.1	0.3	8.3	0.5	4.2	0.4	12.5	1.5
WRIA 28	8.1	0.3	20.9	0.5	29.8	4.2	81.3	6.9	25.6	4.6	87.6	9.1
WRIA 29	5.2	0.4	6.0	0.5	0.9	0.2	2.4	0.2	6.4	0.5	8.8	0.7
WRIA 30	44.7	1.4	46.5	1.7	9.6	0.6	13.8	0.7	48.8	1.9	54.5	2.3
WRIA 31	98.3	1.8	99.8	2.3	22.5	0.9	33.3	1.2	105.8	2.9	119.6	3.7
WRIA 32	9.8	0.3	15.2	0.8	8.8	1.2	22.8	1.9	16.8	1.7	35.6	3.4
WRIA 34	132.7	5.3	139.9	6.2	31.0	2.2	50.7	2.8	147.4	7.4	174.4	9.3
WRIA 35	6.4	0.5	7.8	0.6	2.3	0.4	4.9	0.5	8.1	0.8	12.3	1.0

TABLE 17-6 (continued).
ESTIMATED CAPITAL AND O&M COSTS BY WRIA FOR DRY-SEASON NUTRIENT REMOVAL

	Cost ($ millions, 2010)											
	Objective A		Objective B		Objective C		Objective D		Objective E		Objective F	
	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M
WRIA 36	33.8	1.6	36.8	1.9	8.0	1.1	13.6	1.2	38.2	2.4	46.8	2.9
WRIA 37	92.2	3.3	103.6	4.6	26.3	4.6	56.0	5.5	106.8	7.5	152.6	10.1
WRIA 38	5.0	0.4	6.3	0.5	2.1	0.4	4.4	0.4	6.7	0.7	10.6	1.0
WRIA 39	23.5	0.9	28.4	1.9	8.3	1.3	19.5	1.6	28.3	2.0	45.4	3.4
WRIA 40	18.1	0.6	21.0	0.9	6.5	1.4	14.9	1.7	22.1	1.9	35.1	2.6
WRIA 41	70.3	2.3	75.0	2.8	18.0	1.4	29.2	1.8	79.2	3.7	95.3	4.8
WRIA 42	11.6	0.6	12.4	0.7	2.4	0.2	3.4	0.3	12.9	0.8	14.5	0.9
WRIA 43	20.4	1.1	22.8	1.3	5.4	0.9	10.2	1.0	23.7	1.7	31.2	2.2
WRIA 44	7.9	0.5	9.6	0.6	2.9	0.6	6.5	0.7	10.0	1.0	15.7	1.3
WRIA 45	35.8	1.4	39.4	1.9	10.0	1.3	17.6	1.5	42.1	2.6	53.8	3.4
WRIA 47	7.2	0.3	8.1	0.4	1.5	0.3	3.3	0.3	8.1	0.6	11.0	0.8
WRIA 48	8.8	0.5	9.8	0.6	1.9	0.3	3.6	0.3	10.2	0.7	12.8	0.9
WRIA 49	13.9	0.8	16.2	1.1	2.7	0.5	6.9	0.7	16.8	1.3	23.2	1.8
WRIA 50	10.1	0.5	10.6	0.5	2.0	0.2	2.9	0.2	11.0	0.5	12.2	0.6
WRIA 52	2.0	0.1	2.2	0.1	0.4	0.0	0.5	0.0	2.2	0.1	2.4	0.2
WRIA 53	2.6	0.2	2.8	0.2	0.5	0.1	0.6	0.1	2.9	0.2	3.1	0.2
WRIA 54	38.0	0.0	41.8	0.0	0.2	0.0	51.3	2.7	19.1	0.1	72.7	6.4
WRIA 55	3.8	0.3	4.0	0.3	0.7	0.1	0.9	0.1	4.1	0.3	4.5	0.3
WRIA 56	52.8	2.2	56.0	2.6	9.9	1.0	16.2	1.2	58.3	3.0	67.0	3.6
WRIA 60	0.8	0.1	0.9	0.1	0.1	0.0	0.2	0.0	0.9	0.1	1.0	0.1
WRIA 61	2.0	0.1	2.2	0.1	0.4	0.0	0.5	0.0	2.2	0.1	2.4	0.2
WRIA 62	16.9	0.9	19.1	1.0	5.1	0.5	8.7	0.7	20.3	1.3	25.6	1.7

17.4 CONCLUSIONS

17.4.1 Nitrogen Removal

For nitrogen removal, seasonal operation is slightly more cost-effective (per pound of nitrogen removed) than year-round operation. Year-round removal requires significantly more capital investment to upgrade treatment facilities. However, seasonal removal generally would provide only about 60 percent of the nitrogen removal provided by year-round removal, on an annual mass basis.

Implementing nitrogen removal generally would slightly reduce the amount of sludge produced at a treatment plant (up to 3 percent). Reducing nitrogen to 3 mg/L, however, generally requires the addition of a carbon substrate, which would produce additional sludge—up to 5 percent above existing rates.

Energy consumption for nitrogen removal would be significant. Reducing the TIN effluent concentration statewide to less than 8 mg/L would require approximately two to three times the amount of electrical energy currently used by municipal wastewater treatment facilities. Moreover, existing energy recovery processes at treatment facilities that rely on the production of methane gas from sludge would produce approximately 5 to 10 percent less energy as a consequence of the removal of nitrogen.

17.4.2 Phosphorus Removal

For phosphorus removal, seasonal removal is generally less cost-effective (per pound of phosphorus removed) than year-round removal. Both approaches require about the same capital investment to upgrade treatment facilities, but seasonal removal generally would provide only about 60 percent of the phosphorus removal provided by year-round removal, on an annual mass basis.

Phosphorus removal by chemical precipitation produces significantly more sludge than existing processes—approximately 25 to 35 percent more.

Energy consumption would increase for phosphorus removal, but significantly less than for nitrogen removal. Reducing the TP effluent concentration statewide to less than 1 mg/L would increase treatment plant electrical energy consumption by approximately 15 to 20 percent.

CHAPTER 18.
TREATMENT REQUIREMENTS AND COSTS FOR RECLAIMED WASTEWATER

This chapter identifies process upgrades and associated costs required to upgrade existing treatment plants so that the effluent meets state requirements for reclaimed water used for groundwater recharge.

18.1 APPLICABLE STANDARDS

The State of Washington at Chapter 90 Article 90.46 of the Revised Code of Washington (90.46 RCW) defines reclaimed water as "effluent derived in any part from wastewater with a domestic wastewater component that has been adequately and reliably treated, so that it can be used for beneficial purposes. Reclaimed water is not considered a wastewater." The state's Reclaimed Water Reclamation and Reuse Standards of 1997 define four classes of reclaimed water:

- Class A—Reclaimed water that is oxidized, coagulated, filtered and disinfected, with the median number of total coliform organisms in the wastewater after disinfection over 7 days not exceeding 2.2 per 100 milliliters and the number of total coliform organisms in any sample not exceeding 23 per 100 milliliters.
- Class B—Reclaimed water that is oxidized and disinfected, with the median number of total coliform organisms in the wastewater after disinfection over 7 days not exceeding 2.2 per 100 milliliters and the number of total coliform organisms in any sample not exceeding 23 per 100 milliliters.
- Class C—Reclaimed water that is oxidized and disinfected, with the median number of total coliform organisms in the wastewater after disinfection over 7 days not exceeding 23 per 100 milliliters and the number of total coliform organisms in any sample not exceeding 240 per 100 milliliters.
- Class D—Reclaimed water that is oxidized and disinfected, with the median number of total coliform organisms in the wastewater after disinfection over 7 days not exceeding 240 per 100 milliliters.

The term "oxidized" is defined by the standard as "wastewater in which organic matter has been stabilized such that the biochemical oxygen demand (BOD) does not exceed 30 mg/L and the total suspended solids (TSS) do not exceed 30 mg/L, is non-putrescible and contains dissolved oxygen." The definition does not include any limits on nutrients. An oxidized wastewater does not mean that ammonia has been oxidized.

In practice, conventional secondary treatment achieves oxidized wastewater, so only Class A reclaimed water requires a level of treatment prior to disinfection that is greater than conventional secondary treatment. Class B, C and D reclaimed waters require only secondary treatment and differ only in concentration of total coliform bacteria remaining in the wastewater after disinfection.

The standards limit nutrient concentrations for some specific uses of reclaimed water, including groundwater recharge by surface percolation, and direct potable water aquifer recharge. The standard for reclaimed water to be used for groundwater recharge by surface percolation requires a nitrogen removal treatment process beyond that provided by conventional secondary treatment; however, no numeric values or performance criteria are stipulated.

A draft regulation for reclaimed water (included in revised 1997 standards issued for public comment in 2010 as WAC Chapter 173-219) would require that median nitrogen concentration in the reclaimed water after disinfection over 30 days not exceed 10 mg/L and that no single sample exceed 15 mg/L.

18.2 EVALUATION APPROACH

18.2.1 Technology Assumptions

The evaluation of water reclamation for this report is based on the existing 1997 standards for Class A reclaimed water to be used for groundwater recharge by surface percolation, as well as the draft new standard that would establish a 10-mg/L limit on monthly average concentration. Nutrient removal Objective A would reduce nitrogen to < 8 mg/L, so it was assumed that the Objective A improvements would be implemented for all plants. Additional improvements assumed to achieve Class A standards depend on whether the plant as upgraded to achieve Objective A includes MBR treatment:

- For plants with MBR treatment after upgrades to achieve Objective A, the following additional processes would be required:
  - Upgrade or replacement of the disinfection process to a UV process that reliably achieves Class A standards
  - A post-chlorination process using bulk-delivered sodium hypochlorite to maintain a minimum chlorine residual of 0.5 mg/L to the point of application of the water for recharge
- For plants without MBR treatment after upgrades to achieve Objective A, the following additional processes would be required:
  - Upgrade or replacement of the disinfection process to a UV process that reliably achieves Class A standards
  - A post-chlorination process using bulk-delivered sodium hypochlorite to maintain a minimum chlorine residual of 0.5 mg/L to the point of application of the water for recharge
  - A new filtration process with coagulation/flocculation (only for upgraded plants that would not include membrane bioreactors)

In this report, plants that would include MBR treatment when upgraded to achieve Objective A are referred to as "membrane plants" and those that would not include MBR treatment after upgrade are referred to as "non-membrane plants." Existing plant types are grouped in these two categories as follows:

- Membrane plants—Plants that currently use conventional activated sludge, trickling filters, trickling filter-solids contact, rotating biological contactors, high purity oxygen or MBR
- Non-membrane plants—Plants that currently use extended aeration, sequencing batch reactors or lagoons.

Table 18-1 lists the design criteria for the assumed upgrades for each category. Cost estimates were developed for producing Class A reclaimed water year-round and seasonally for the two categories of upgraded plants. Four plant maximum-month capacities were evaluated: 0.5 mgd, 5 mgd, 50 mgd and 220 mgd. The evaluation assumed that existing methods for wastewater disposal would be retained as a backup should effluent fail to meet reclaimed water requirements, so no costs were developed for standby or redundant process equipment. Costs for storage and distribution of reclaimed water from the treatment plant to the point of application for groundwater recharge are beyond the scope of this project.

TABLE 18-1.
DESIGN CRITERIA FOR PROCESSES TO PROVIDE CLASS A RECLAIMED WATER

Process	Design Criterion	
	Non-Membrane Plants	Membrane Plants
Disinfection		
• Turbidity	2 NTU mo. average; 5 NTU max	0.2 NTU mo. average; 0.5 NTU max
• UV transmittance	55%	65%
• Min UV Dose @ 254 nm	100 mJ/cm^2	80 mJ/cm^2
• Bacteriological Quality	7-day median total coliform equal or less than 2.2 MPN/100 mL and no sample above 23 MPN/100 mL	7-day median total coliform equal or less than 2.2 MPN/100 mL and no sample above 23 MPN/100 mL
Assumed Post-Chlorination System		
• Total chlorine residual after 20 minutes contact	2 mg/L chlorine as NaOCL	2 mg/L chlorine as NaOCL
Filtration w/Coagulation		
• Rapid Mix	1 second @ peak hour flow	Not applicable
• Coagulant dosing	10 mg/L alum	Not applicable
• Sand filtration rate	5 gpm/sq. ft. @ peak daily flow including recycle	Not applicable

18.2.2 Cost Approach

CapdetWorks was used to estimate capital and annual O&M costs for year-round and seasonal reclaimed water upgrades for each category of plant. O&M costs include labor, materials, chemicals and energy. Annualized capital costs over 20 years were calculated assuming a 3-percent discount rate. Cost curves and best-fit equations of unit cost (per plant capacity) vs. plant capacity were then used to estimate annualized costs for the three plant capacities used in the nutrient-removal evaluation for each type of existing plant. Reclaimed water upgrade costs were then calculated as a percentage of nutrient removal upgrade costs estimated earlier in this report.

18.3 YEAR-ROUND RECLAIMED WATER UPGRADE COST ESTIMATES

18.3.1 Non-Membrane Plants

Table 18-2 lists unit capital costs for the year-round reclaimed water upgrades for non-membrane plants. Figure 18-1 shows the cost curve for these estimates and a best-fit parametric equation based on the data. Table 18-3 lists unit O&M costs for these upgrades; the generalized O&M cost curve and best-fit equation are shown on Figure 18-2. Annualized cost results are presented in Table 18-4 and Figure 18-3.

18.3.2 Membrane Plants

Table 18-5 lists unit capital costs for the year-round reclaimed water upgrades for membrane plants. Figure 18-4 shows the cost curve for these estimates and a best-fit parametric equation based on the data. Table 18-6 lists unit O&M costs for these upgrades; the O&M cost curve and best-fit equation are shown on Figure 18-5. Annualized cost results are summarized in Table 18-7 and Figure 18-6.

TABLE 18-2.
ESTIMATED CAPITAL COSTS FOR YEAR-ROUND RECLAIMED WATER UPGRADES FOR NON-MEMBRANE PLANTS

	Estimated Capital Cost per gpd of Maximum-Month Capacity			
	0.5 mgd Plant	5 mgd Plant	50 mgd Plant	220 mgd Plant
Coagulation /Filtration	$4.10	$1.79	$1.02	$0.66
UV Disinfection	$5.29	$6.63	$4.56	$4.08
Post-Disinfection Chlorination	$1.67	$0.33	$0.16	$0.09
Total	**$11.06**	**$8.76**	**$5.71**	**$4.55**

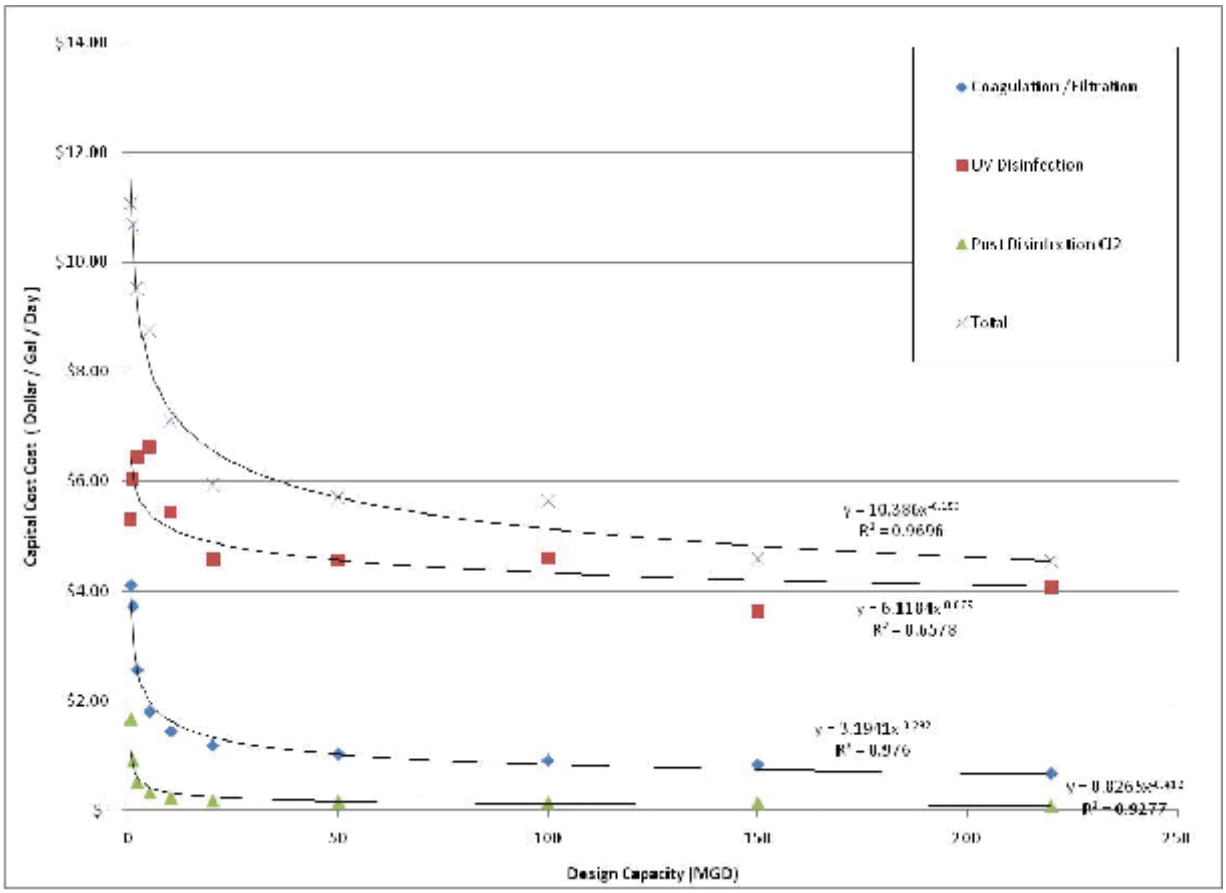

Figure 18-1. Capital Costs for Year-Round Reclaimed Water Upgrades for Non-Membrane Plants

TABLE 18-3.
ESTIMATED ANNUAL O&M COSTS FOR YEAR-ROUND RECLAIMED WATER UPGRADES FOR NON-MEMBRANE PLANTS

	0.5 mgd Plant	5 mgd Plant	50 mgd Plant	220 mgd Plant
Annual O&M Cost per gpd of Maximum-Month Capacity [a]	$0.99	$0.23	$0.15	$0.09

a. Includes labor, materials, chemicals and energy

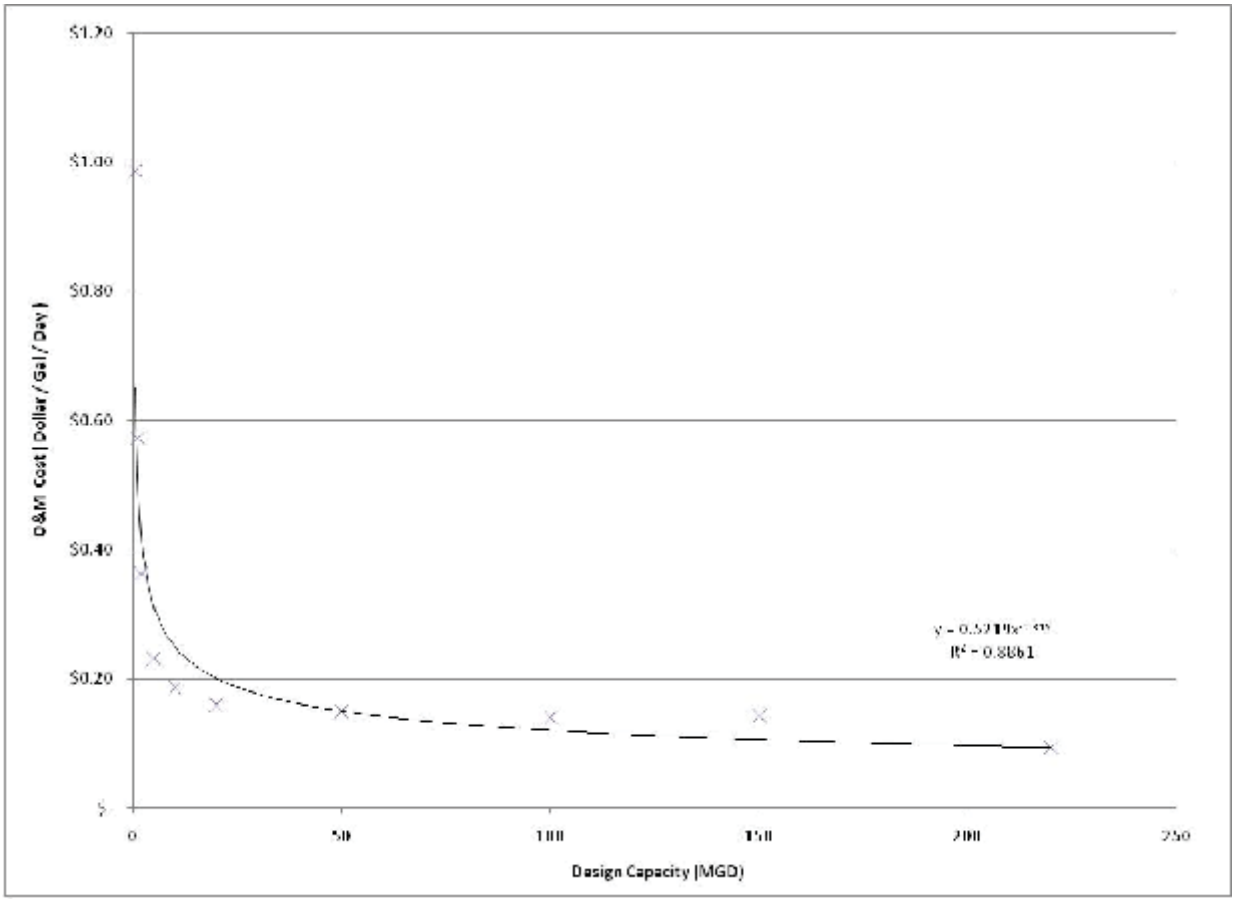

Figure 18-2. Annual O&M Costs for Year-Round Reclaimed Water Upgrades for Non-Membrane Plants

TABLE 18-4.
ESTIMATED ANNUALIZED CAPITAL AND O&M COSTS FOR YEAR-ROUND RECLAIMED WATER UPGRADES FOR NON-MEMBRANE PLANTS

	Estimated Cost per gpd of Maximum-Month Capacity			
	0.5 mgd Plant	5 mgd Plant	50 mgd Plant	220 mgd Plant
Annualized Capital Cost	$0.74	$0.59	$0.38	$0.31
Annual O&M Cost	$0.99	$0.23	$0.15	$0.09
Total Annualized Cost	**$1.73**	**$0.82**	**$0.53**	**$0.38**

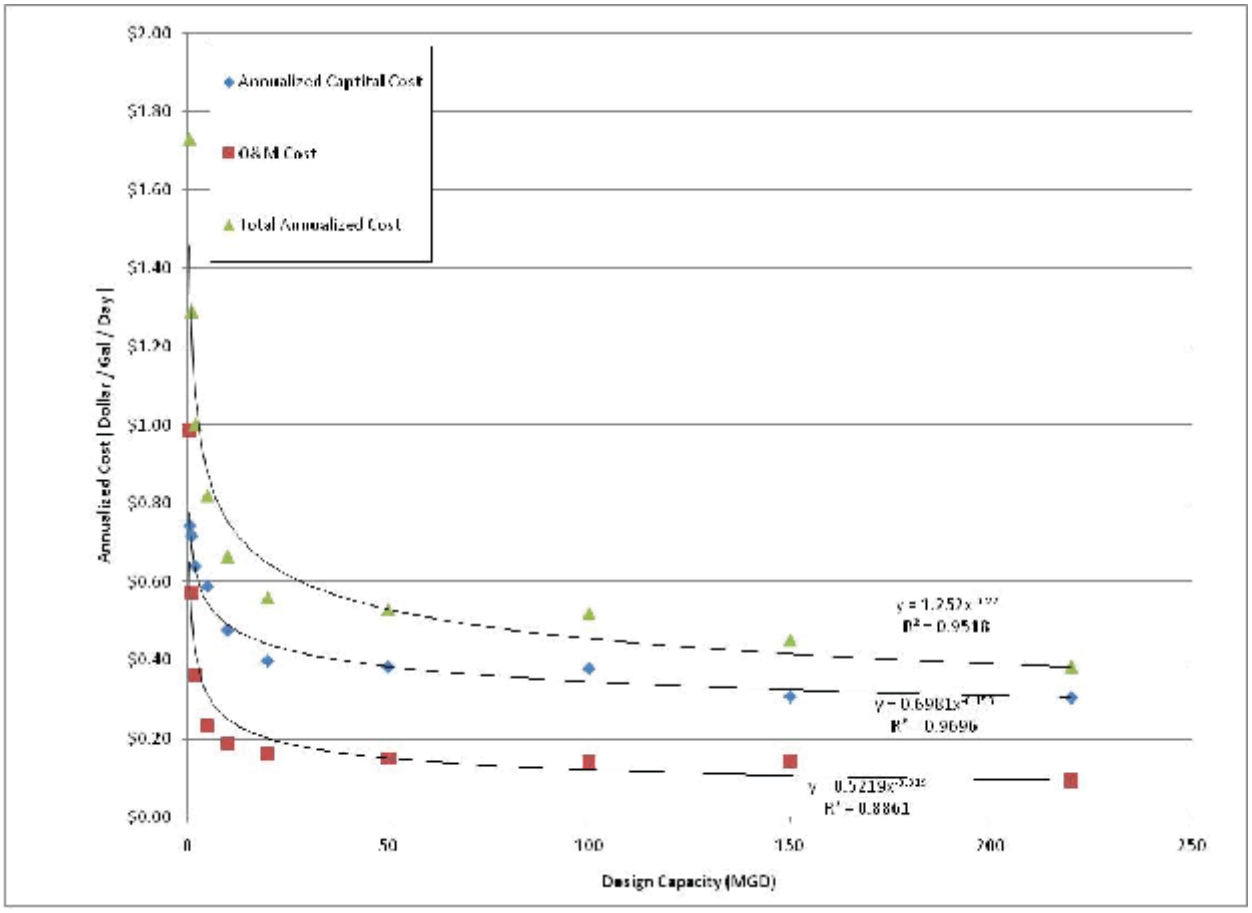

Figure 18-3. Annualized Capital and O&M Costs for Year-Round Reclaimed Water Upgrades for Non-Membrane Plants

TABLE 18-5.
ESTIMATED CAPITAL COSTS FOR YEAR-ROUND RECLAIMED WATER UPGRADES FOR MEMBRANE PLANTS

	Estimated Capital Cost per gpd of Maximum-Month Capacity			
	0.5 mgd Plant	5 mgd Plant	50 mgd Plant	220 mgd Plant
UV Disinfection	$5.29	$6.63	$4.56	$4.08
Post-Disinfection Chlorination	$1.67	$0.33	$0.16	$0.09
Total	**$6.96**	**$6.96**	**$4.70**	**$4.02**

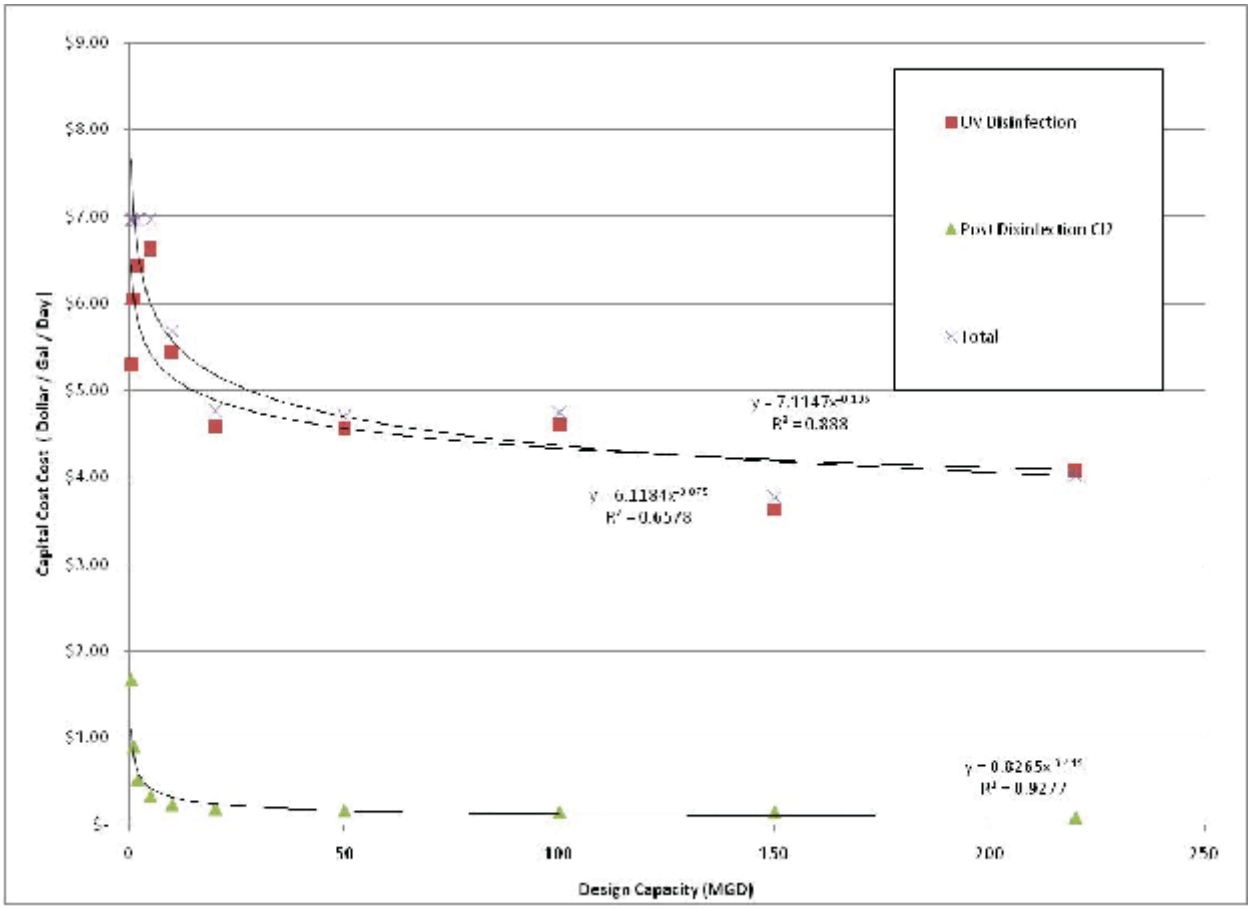

Figure 18-4. Capital Costs for Year-Round Reclaimed Water Upgrades for Membrane Plants

TABLE 18-6.
ESTIMATED ANNUAL O&M COSTS FOR YEAR-ROUND RECLAIMED WATER UPGRADES FOR MEMBRANE PLANTS

	0.5 mgd Plant	5 mgd Plant	50 mgd Plant	220 mgd Plant
Annual O&M Cost per gpd of Maximum-Month Capacity [a]	$0.20	$0.14	$0.12	$0.11

a. Includes labor, materials, chemicals and energy

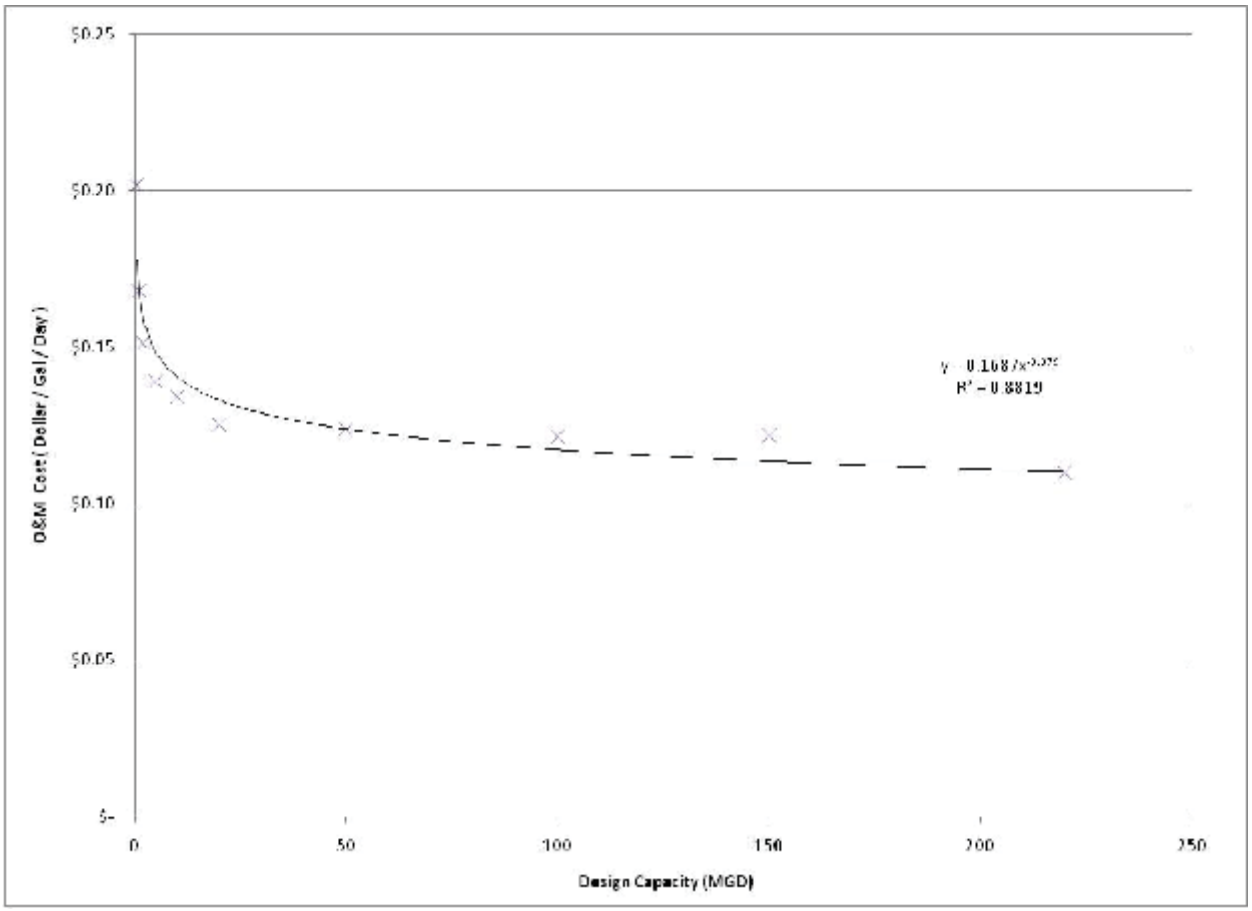

Figure 18-5. Annual O&M Costs for Year-Round Reclaimed Water Upgrades for Membrane Plants

TABLE 18-7.
ESTIMATED ANNUALIZED CAPITAL AND O&M COSTS FOR YEAR-ROUND RECLAIMED WATER UPGRADES FOR MEMBRANE PLANTS

	Estimated Cost per gpd of Maximum-Month Capacity			
	0.5 mgd Plant	5 mgd Plant	50 mgd Plant	220 mgd Plant
Annualized Capital Cost	$0.47	$0.47	$0.32	$0.27
Annual O&M Cost	$0.20	$0.14	$0.12	$0.11
Total Annualized Cost	**$0.67**	**$0.61**	**$0.44**	**$0.38**

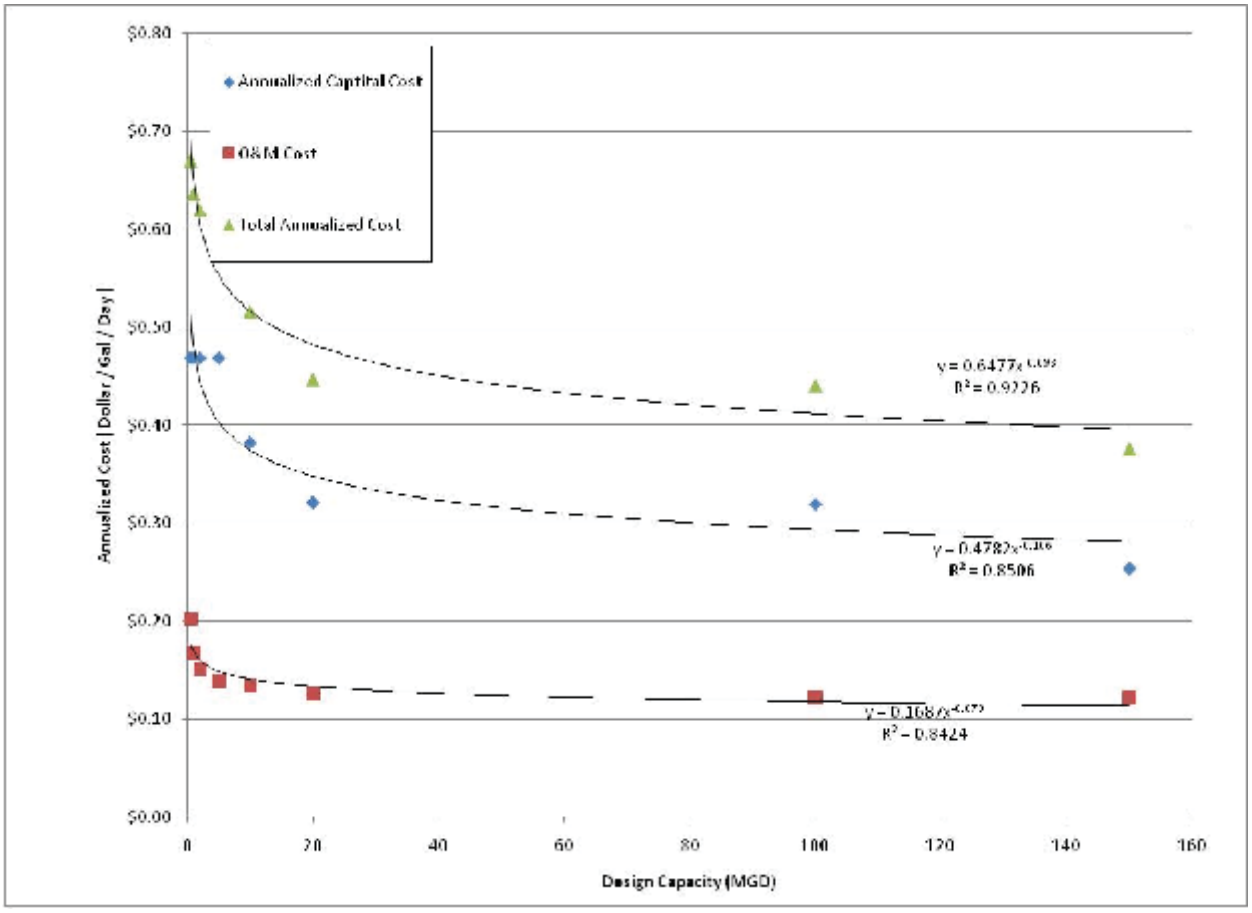

Figure 18-6. Annualized Capital and O&M Costs for Year-Round Reclaimed Water Upgrades for Membrane Plants

18.3.3 Extended Aeration Plants

Tables 18-8 through 18-11 show annualized capital and annual O&M cost estimates for upgrading both types of extended aeration plants (mechanical aeration and diffused aeration) to achieve Objective A nutrient removal and to provide Class A reclaimed water. The cost of the reclaimed water upgrade is also shown as a percent of the nitrogen removal upgrade cost.

TABLE 18-8.
ANNUALIZED CAPITAL COSTS FOR YEAR-ROUND NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR EXTENDED AERATION PLANTS (MECHANICAL AERATION)

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Estimated Annualized Capital Costs for Nitrogen Removal Upgrade	$351,414	$1,656,556	$16,134,708
Estimated Annualized Capital Costs for Reclaimed Water Upgrade	$698,100	$4,908,148	$34,507,829
Total	**$1,049,514**	**$6,564,704**	**$50,642,537**
% Cost Increase for Reclaimed Water Upgrade	199%	296%	214%

TABLE 18-9.
ANNUAL O&M COSTS FOR YEAR-ROUND NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR EXTENDED AERATION PLANTS (MECHANICAL AERATION)

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Estimated Annual O&M Costs for Nitrogen Removal Upgrade	$234,218	$142,715	($2,068,685)
Estimated Annual O&M Costs for Reclaimed Water Upgrade	$521,900	$2,121,228	$8,621,589
Total	**$756,118**	**$2,263,943**	**$6,552,904**
% Cost Increase for Reclaimed Water Upgrade	223%	1486%	-417%

TABLE 18-10.
ANNUALIZED CAPITAL COSTS FOR YEAR-ROUND NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR EXTENDED AERATION PLANTS (DIFFUSED AERATION)

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Estimated Annualized Capital Costs for Nitrogen Removal Upgrade	$78,303	$554,242	$2,298,201
Estimated Annualized Capital Costs for Reclaimed Water Upgrade	$698,100	$4,908,148	$34,507,829
Total	**$776,403**	**$5,462,390**	**$36,806,030**
% Cost Increase for Reclaimed Water Upgrade	892%	886%	1502%

TABLE 18-11.
ANNUAL O&M COSTS FOR YEAR-ROUND NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR EXTENDED AERATION PLANTS (DIFFUSED AERATION)

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Estimated Annual O&M Costs for Nitrogen Removal Upgrade	$19,584	($526,175)	($574,741)
Estimated Annual O&M Costs for Reclaimed Water Upgrade	$521,900	$2,121,228	$8,621,589
Total	**$541,484**	**$1,595,053**	**$8,046,848**
% Cost Increase for Reclaimed Water Upgrade	2665%	-403%	-1500%

18.3.4 Conventional Activated Sludge Plants

Tables 18-12 and 18-13 show annualized capital and annual O&M cost estimates for upgrading conventional activated sludge plants to achieve Objective A nutrient removal and to provide Class A reclaimed water. The cost of the reclaimed water upgrade is also shown as a percent of the nitrogen removal upgrade cost.

TABLE 18-12.
ANNUALIZED CAPITAL COSTS FOR YEAR-ROUND NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR CONVENTIONAL ACTIVATED SLUDGE PLANTS

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Estimated Annualized Capital Costs for Nitrogen Removal Upgrade	$487,073	$3,341,694	$36,630,838
Estimated Annualized Capital Costs for Reclaimed Water Upgrade	$428,200	$3,354,646	$37,763,501
Total	**$915,273**	**$6,696,340**	**$74,394,339**
% Cost Increase for Reclaimed Water Upgrade	88%	100%	103%

TABLE 18-13.
ANNUAL O&M COSTS FOR YEAR-ROUND NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR CONVENTIONAL ACTIVATED SLUDGE PLANTS

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Estimated Annual O&M Costs for Nitrogen Removal Upgrade	$262,642	$1,451,579	$13,597,000
Estimated Annual O&M Costs for Reclaimed Water Upgrade	$168,700	$1,406,420	$17,033,156
Total	**$431,342**	**$2,857,999**	**$30,630,156**
% Cost Increase for Reclaimed Water Upgrade	64%	97%	125%

18.3.5 Sequencing Batch Reactors

Tables 18-14 and 18-15 show annualized capital and annual O&M cost estimates for upgrading sequencing batch reactor plants to achieve Objective A nutrient removal and to provide Class A reclaimed water. The cost of the reclaimed water upgrade is also shown as a percent of the nitrogen removal upgrade cost.

TABLE 18-14.
ANNUALIZED CAPITAL COSTS FOR YEAR-ROUND NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR SEQUENCING BATCH REACTOR PLANTS

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Estimated Annualized Capital Costs for Nitrogen Removal Upgrade	$0	$0	$0
Estimated Annualized Capital Costs for Reclaimed Water Upgrade	$388,101	$1,255,712	$4,908,148
Total	**$388,101**	**$1,255,712**	**$4,908,148**
% Cost Increase for Reclaimed Water Upgrade	Undefined	Undefined	Undefined

TABLE 18-15.
ANNUAL O&M COSTS FOR YEAR-ROUND NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR SEQUENCING BATCH REACTOR PLANTS

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Estimated Annual O&M Costs for Nitrogen Removal Upgrade	$4,615	$11,368	$43,332
Estimated Annual O&M Costs for Reclaimed Water Upgrade	$342,184	$796,003	$2,121,228
Total	**$346,799**	**$807,371**	**$2,164,560**
% Cost Increase for Reclaimed Water Upgrade	7415%	7002%	4895%

18.3.6 Trickling Filter, Trickling Filter/Solids Contact and Rotating Biological Contactor Plants

Tables 18-16 through 18-21 show annualized capital and annual O&M cost estimates for upgrading trickling filter, trickling filter/solids contact and rotating biological contactor plants to achieve Objective A nutrient removal and to provide Class A reclaimed water. The cost of the reclaimed water upgrade is also shown as a percent of the nitrogen removal upgrade cost.

TABLE 18-16.
ANNUALIZED CAPITAL COSTS FOR YEAR-ROUND NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR TRICKLING FILTER PLANTS

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Estimated Annualized Capital Costs for Nitrogen Removal Upgrade	$601,194	$4,278,563	$42,098,874
Estimated Annualized Capital Costs for Reclaimed Water Upgrade	$428,200	$3,354,646	$37,763,501
Total	**$1,029,394**	**$7,633,209**	**$79,862,375**
% Cost Increase for Reclaimed Water Upgrade	71%	78%	90%

TABLE 18-17.
ANNUAL O&M COSTS FOR YEAR-ROUND NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR TRICKLING FILTER PLANTS

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Estimated Annual O&M Costs for Nitrogen Removal Upgrade	$328,594	$1,672,797	$13,518,789
Estimated Annual O&M Costs for Reclaimed Water Upgrade	$168,700	$1,406,420	$17,033,156
Total	**$497,294**	**$3,079,217**	**$30,551,945**
% Cost Increase for Reclaimed Water Upgrade	51%	84%	126%

TABLE 18-18.
ANNUALIZED CAPITAL COSTS FOR YEAR-ROUND NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR ROTATING BIOLOGICAL CONTACTOR PLANTS

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Estimated Annualized Capital Costs for Nitrogen Removal Upgrade	$601,523	$4,298,964	$42,622,884
Estimated Annualized Capital Costs for Reclaimed Water Upgrade	$428,200	$3,354,646	$37,763,501
Total	**$1,029,723**	**$7,653,610**	**$80,386,385**
% Cost Increase for Reclaimed Water Upgrade	71%	78%	89%

TABLE 18-19.
ANNUAL O&M COSTS FOR YEAR-ROUND NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR ROTATING BIOLOGICAL CONTACTOR PLANTS

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Estimated Annual O&M Costs for Nitrogen Removal Upgrade	$389,616	$1,824,178	$14,526,119
Estimated Annual O&M Costs for Reclaimed Water Upgrade	$168,700	$1,406,420	$17,033,156
Total	**$558,316**	**$3,230,598**	**$31,559,275**
% Cost Increase for Reclaimed Water Upgrade	43%	77%	117%

TABLE 18-20.
ANNUALIZED CAPITAL COSTS FOR YEAR-ROUND NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR TRICKLING FILTER/SOLIDS CONTACT PLANTS

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Estimated Annualized Capital Costs for Nitrogen Removal Upgrade	$507,744	$3,870,296	$38,592,858
Estimated Annualized Capital Costs for Reclaimed Water Upgrade	$428,200	$3,354,646	$37,763,501
Total	**$935,944**	**$7,224,942**	**$76,356,359**
% Cost Increase for Reclaimed Water Upgrade	84%	87%	98%

TABLE 18-21.
ANNUAL O&M COSTS FOR YEAR-ROUND NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR TRICKLING FILTER/SOLIDS CONTACT PLANTS

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Estimated Annual O&M Costs for Nitrogen Removal Upgrade	$203,721	$1,409,147	$11,856,412
Estimated Annual O&M Costs for Reclaimed Water Upgrade	$168,700	$1,406,420	$17,033,156
Total	**$372,421**	**$2,815,567**	**$28,889,568**
% Cost Increase for Reclaimed Water Upgrade	83%	100%	144%

18.3.7 Membrane Biological Reactor Plants

Tables 18-22 and 18-23 show annualized capital and annual O&M cost estimates for upgrading MBR plants to achieve Objective A nutrient removal and to provide Class A reclaimed water. The cost of the reclaimed water upgrade is also shown as a percent of the nitrogen removal upgrade cost.

TABLE 18-22.
ANNUALIZED CAPITAL COSTS FOR YEAR-ROUND NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR MEMBRANE BIOREACTOR PLANTS

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Estimated Annualized Capital Costs for Nitrogen Removal Upgrade	$0	$0	$0
Estimated Annualized Capital Costs for Reclaimed Water Upgrade	$428,200	$3,354,646	$26,281,289
Total	**$428,200**	**$3,354,646**	**$26,281,289**
% Cost Increase for Reclaimed Water Upgrade	undefined	undefined	undefined

TABLE 18-23.
ANNUAL O&M COSTS FOR YEAR-ROUND NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR MEMBRANE BIOREACTOR PLANTS

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Estimated Annual O&M Costs for Nitrogen Removal Upgrade	$ 0	$0	$0
Estimated Annual O&M Costs for Reclaimed Water Upgrade	$168,700	$1,406,420	$11,725,060
Total	**$168,700**	**$1,406,420**	**$11,725,060**
% Cost Increase for Reclaimed Water Upgrade	undefined	undefined	undefined

18.3.8 High-Purity Oxygen Activated Sludge Plants

Tables 18-24 and 18-25 show annualized capital and annual O&M cost estimates for upgrading high-purity oxygen activated sludge plants to achieve Objective A nutrient removal and to provide Class A reclaimed water. The cost of the reclaimed water upgrade is also shown as a percent of the nitrogen removal upgrade cost.

TABLE 18-24.
ANNUALIZED CAPITAL COSTS FOR YEAR-ROUND NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR HIGH-PURITY OXYGEN ACTIVATED SLUDGE PLANTS

	20-mgd Plant	220-mgd Plant
Estimated Annualized Capital Costs for Nitrogen Removal Upgrade	$5,745,000	$48,960,000
Estimated Annualized Capital Costs for Reclaimed Water Upgrade	$6,234,000	$53,183,000
Total	**$11,979,000**	**$102,143,000**
% Cost Increase for Reclaimed Water Upgrade	109%	109%

TABLE 18-25.
ANNUAL O&M COSTS FOR YEAR-ROUND NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR HIGH-PURITY OXYGEN ACTIVATED SLUDGE PLANTS

	20-mgd Plant	220-mgd Plant
Estimated Annual O&M Costs for Nitrogen Removal Upgrade	$4,172,000	$35,520,000
Estimated Annual O&M Costs for Reclaimed Water Upgrade	$2,663,000	$24,237,000
Total	**$6,835,000**	**$59,757,000**
% Cost Increase for Reclaimed Water Upgrade	64%	68%

18.3.9 Lagoon Plants

Tables 18-26 through 18-29 show annualized capital and annual O&M cost estimates for upgrading both types of lagoon plants (aerated and facultative) to achieve Objective A nutrient removal and to provide Class A reclaimed water. The cost of the reclaimed water upgrade is also shown as a percent of the nitrogen removal upgrade cost.

TABLE 18-26.
ANNUALIZED CAPITAL COSTS FOR YEAR-ROUND NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR FACULTATIVE LAGOON PLANTS

	0.5-mgd Plant	5-mgd Plant	50-mgd Plant
Estimated Annualized Capital Costs for Nitrogen Removal Upgrade	$815,034	$4,073,790	$23,994,247
Estimated Annualized Capital Costs for Reclaimed Water Upgrade	$388,101	$2,728,634	$19,184,268
Total	**$1,203,135**	**$6,802,424**	**$43,178,515**
% Cost Increase for Reclaimed Water Upgrade	48%	67%	80%

TABLE 18-27.
ANNUAL O&M COSTS FOR YEAR-ROUND NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR FACULTATIVE LAGOON PLANTS

	0.5-mgd Plant	5-mgd Plant	50-mgd Plant
Estimated Annual O&M Costs for Nitrogen Removal Upgrade	$665,608	$2,224,005	$7,997,263
Estimated Annual O&M Costs for Reclaimed Water Upgrade	$342,184	$1,390,785	$5,652,753
Total	**$1,007,792**	**$3,614,790**	**$13,650,016**
% Cost Increase for Reclaimed Water Upgrade	51%	63%	71%

TABLE 18-28.
ANNUALIZED CAPITAL COSTS FOR YEAR-ROUND NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR AERATED LAGOON PLANTS

	0.5-mgd Plant	5-mgd Plant	50-mgd Plant
Estimated Annualized Capital Costs for Nitrogen Removal Upgrade	$820,052	$4,106,942	$24,168,643
Estimated Annualized Capital Costs for Reclaimed Water Upgrade	$388,101	$2,728,634	$19,184,268
Total	**$1,208,153**	**$6,835,576**	**$43,352,911**
% Cost Increase for Reclaimed Water Upgrade	47%	66%	79%

TABLE 18-29.
ANNUAL O&M COSTS FOR YEAR-ROUND NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR AERATED LAGOON PLANTS

	0.5-mgd Plant	5-mgd Plant	50-mgd Plant
Estimated Annual O&M Costs for Nitrogen Removal Upgrade	$512,439	$1,321,179	$6,109,993
Estimated Annual O&M Costs for Reclaimed Water Upgrade	$342,184	$1,390,785	$5,652,753
Total	**$854,623**	**$2,711,964**	**$11,762,746**
% Cost Increase for Reclaimed Water Upgrade	67%	105%	93%

18.4 SEASONAL RECLAIMED WATER UPGRADE COST ESTIMATES

18.4.1 Non-Membrane Plants

Table 18-30 lists unit capital costs for the seasonal reclaimed water upgrades for non-membrane plants. Figure 18-7 shows the cost curve for these estimates and a best-fit parametric equation based on the data. Table 18-31 lists unit O&M costs for these upgrades; the generalized O&M cost curve and best-fit equation are shown on Figure 18-8. Annualized cost results are presented in Table 18-32 and Figure 18-9.

18.4.2 Membrane Plants

Table 18-33 lists unit capital costs for the seasonal reclaimed water upgrades for membrane plants. Figure 18-10 shows the cost curve for these estimates and a best-fit parametric equation based on the data. Table 18-34 lists unit O&M costs for these upgrades; the O&M cost curve and best-fit equation are shown on Figure 18-11. Annualized cost results are summarized in Table 18-35 and Figure 18-12.

TABLE 18-30.
ESTIMATED CAPITAL COSTS FOR SEASONAL RECLAIMED WATER UPGRADES FOR NON-MEMBRANE PLANTS

	Estimated Capital Cost per gpd of Maximum-Month Capacity			
	0.5 mgd Plant	5 mgd Plant	50 mgd Plant	220 mgd Plant
Coagulation /Filtration	$3.67	$1.41	$0.76	$0.48
UV Disinfection	$3.17	$4.36	$3.24	$3.05
Post-Disinfection Chlorination	$1.62	$0.29	$0.12	$0.06
Total	**$8.46**	**$6.06**	**$4.08**	**$3.27**

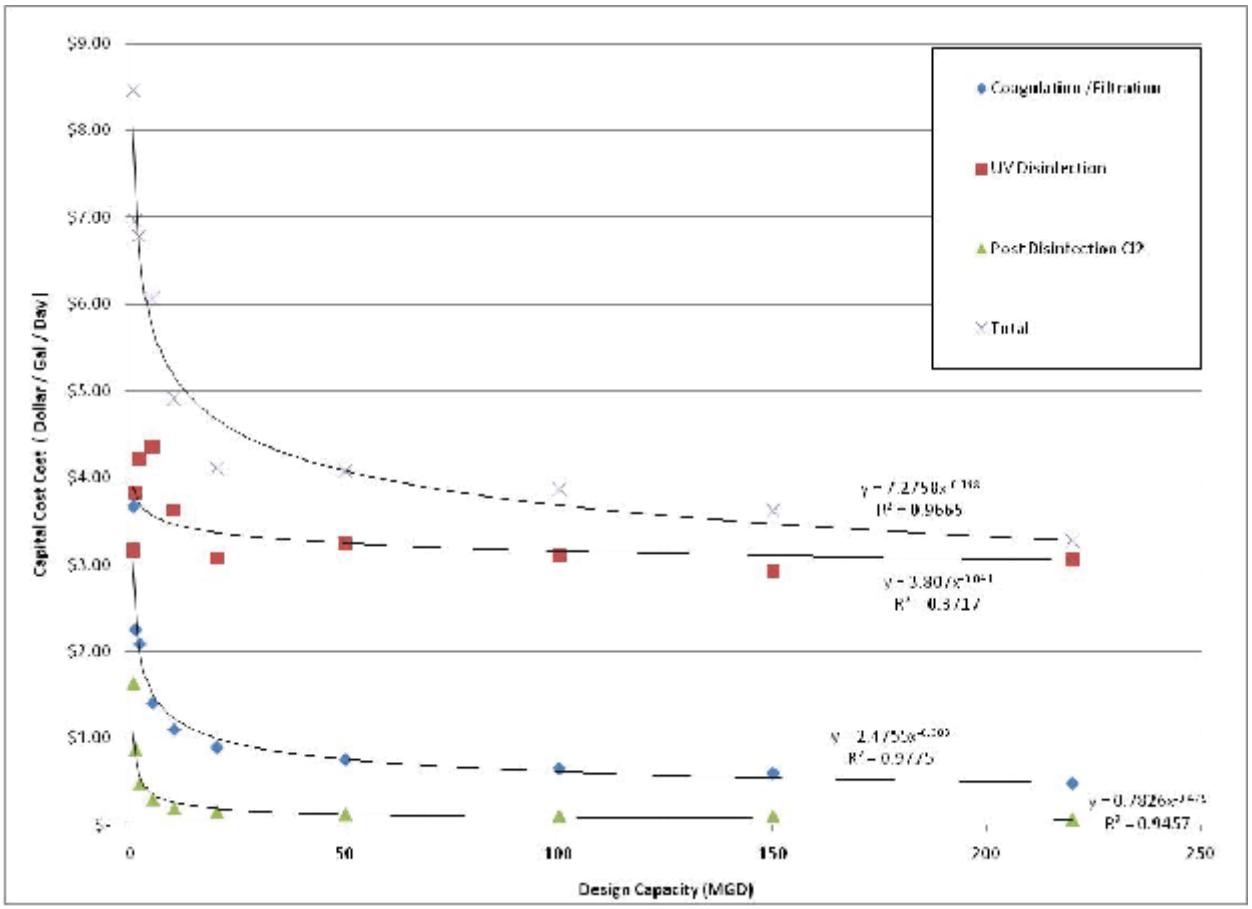

Figure 18-7. Capital Costs for Seasonal Reclaimed Water Upgrades for Non-Membrane Plants

TABLE 18-31.
ESTIMATED ANNUAL O&M COSTS FOR SEASONAL RECLAIMED WATER UPGRADES FOR NON-MEMBRANE PLANTS

	0.5 mgd Plant	5 mgd Plant	50 mgd Plant	220 mgd Plant
Annual O&M Cost per gpd of Maximum-Month Capacity [a]	$0.90	$0.16	$0.08	$0.04

a. Includes labor, materials, chemicals and energy

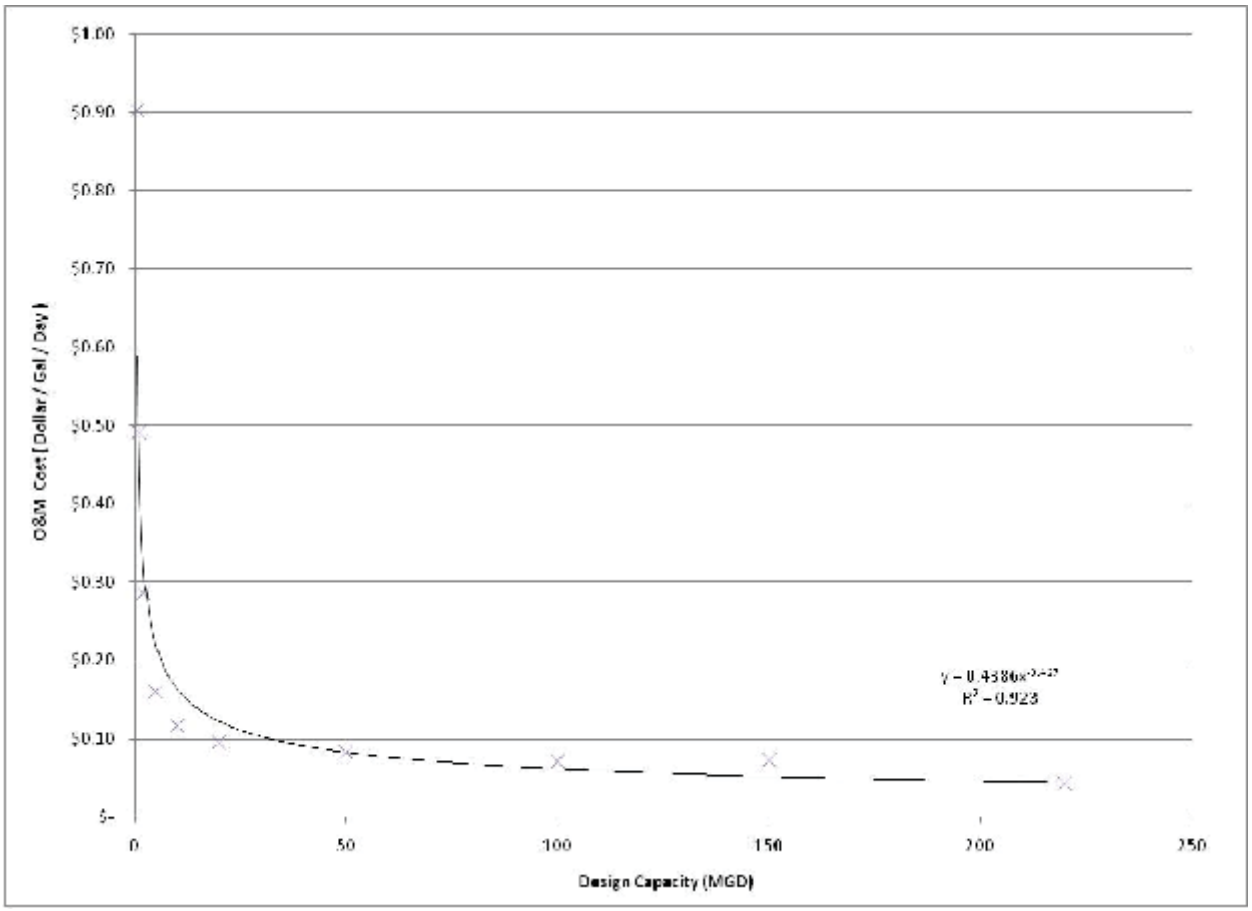

Figure 18-8. Annual O&M Costs for Seasonal Reclaimed Water Upgrades for Non-Membrane Plants

TABLE 18-32.
ESTIMATED ANNUALIZED CAPITAL AND O&M COSTS FOR SEASONAL RECLAIMED WATER UPGRADES FOR NON-MEMBRANE PLANTS

	Estimated Cost per gpd of Maximum-Month Capacity			
	0.5 mgd Plant	5 mgd Plant	50 mgd Plant	220 mgd Plant
Annualized Capital Cost	$0.57	$0.41	$0.27	$0.22
Annual O&M Cost	$0.90	$0.16	$0.08	$0.04
Total Annualized Cost	**$1.47**	**$0.57**	**$0.35**	**$0.24**

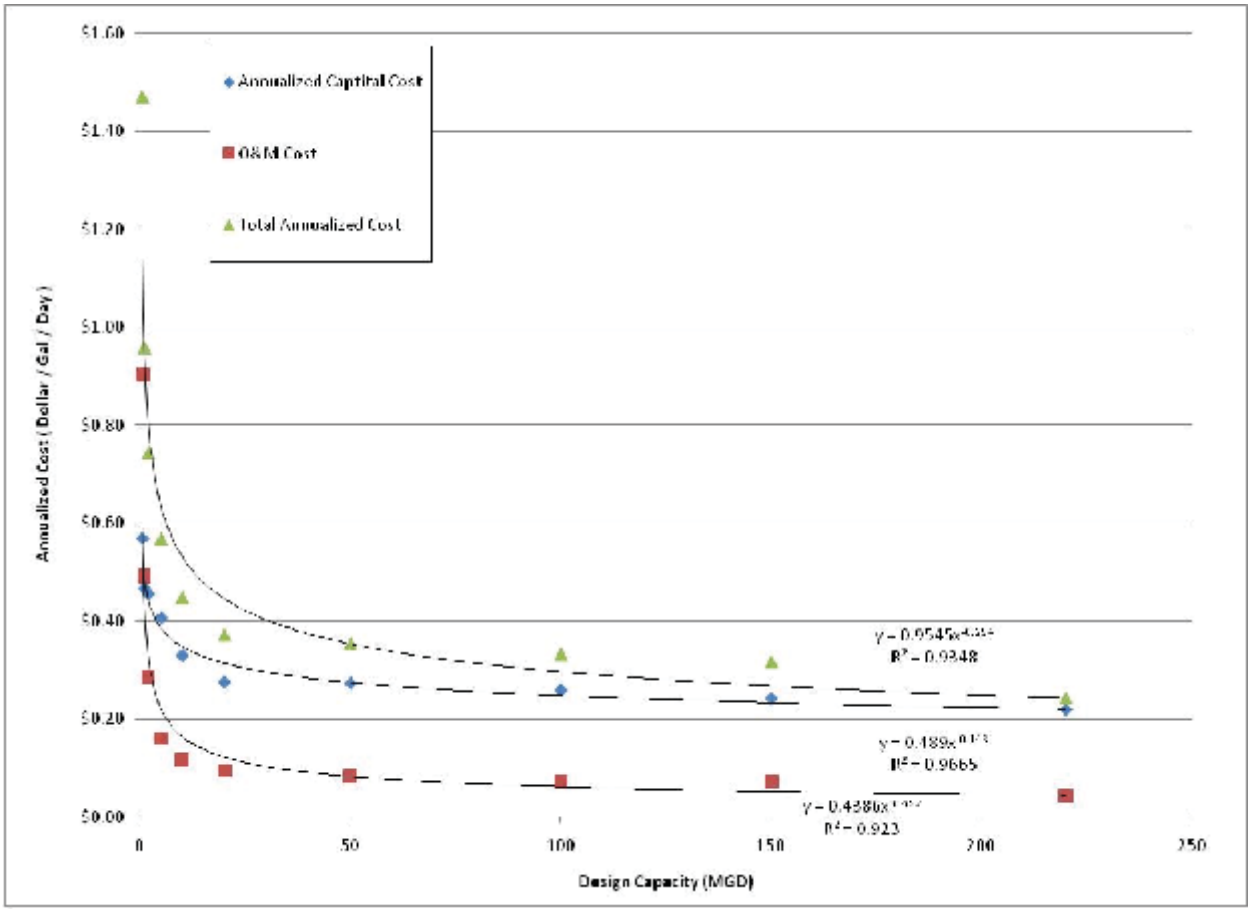

Figure 18-9. Annualized Capital and O&M Costs for Seasonal Reclaimed Water Upgrades for Non-Membrane Plants

TABLE 18-33.
ESTIMATED CAPITAL COSTS FOR SEASONAL RECLAIMED WATER UPGRADES FOR MEMBRANE PLANTS

	Estimated Capital Cost per gpd of Maximum-Month Capacity			
	0.5 mgd Plant	5 mgd Plant	50 mgd Plant	220 mgd Plant
UV Disinfection	$3.17	$4.36	$3.24	$3.05
Post-Disinfection Chlorination	$1.62	$0.29	$0.12	$0.06
Total	**$4.79**	**$4.65**	**$3.33**	**$2.91**

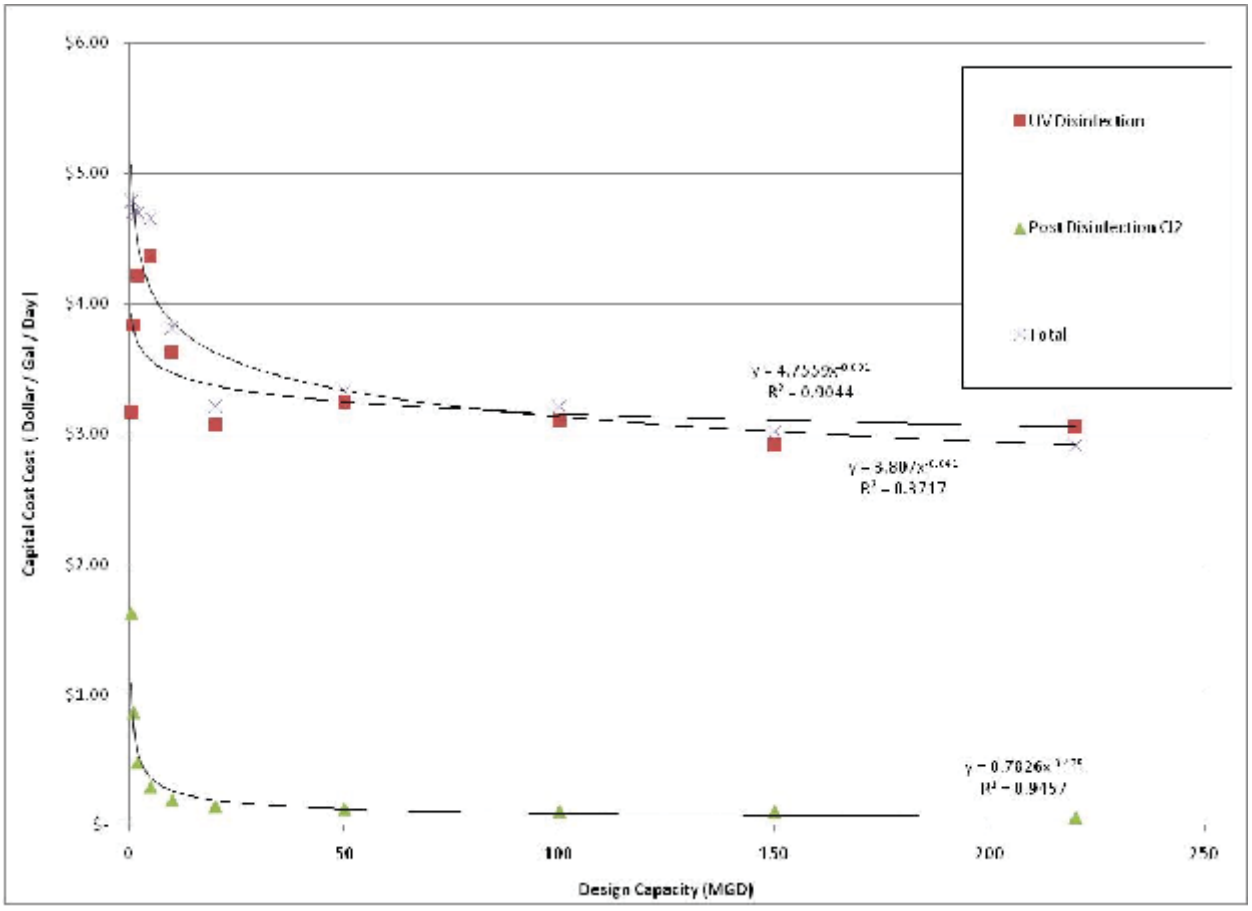

Figure 18-10. Capital Costs for Seasonal Reclaimed Water Upgrades for Membrane Plants

TABLE 18-34.
ESTIMATED ANNUAL O&M COSTS FOR SEASONAL RECLAIMED WATER UPGRADES FOR MEMBRANE PLANTS

	0.5 mgd Plant	5 mgd Plant	50 mgd Plant	220 mgd Plant
Annual O&M Cost per gpd of Maximum-Month Capacity [a]	$0.12	$0.07	$0.06	$0.05

a. Includes labor, materials, chemicals and energy

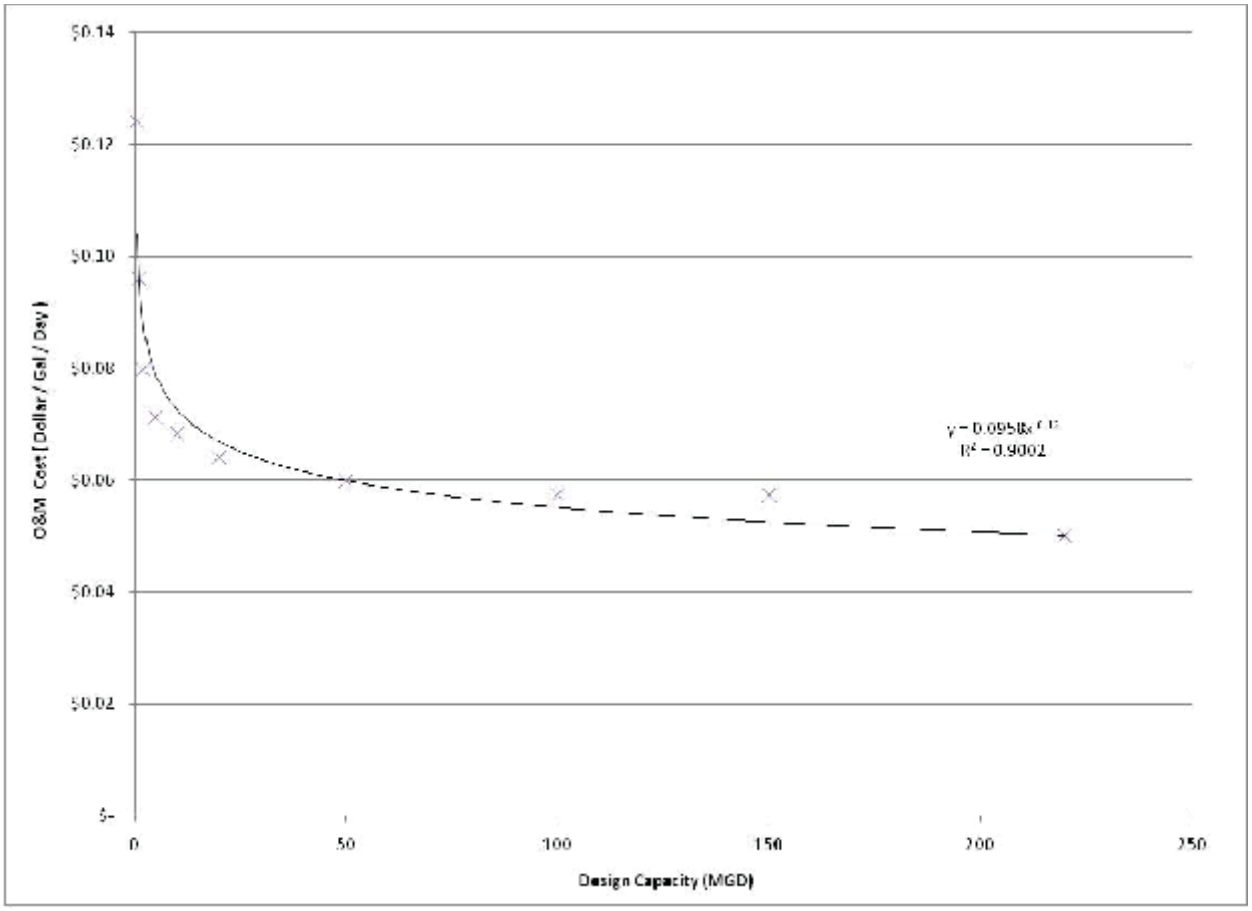

Figure 18-11. Annual O&M Costs for Seasonal Reclaimed Water Upgrades for Membrane Plants

TABLE 18-35.
ESTIMATED ANNUALIZED CAPITAL AND O&M COSTS FOR SEASONAL RECLAIMED WATER UPGRADES FOR MEMBRANE PLANTS

	Estimated Cost per gpd of Maximum-Month Capacity			
	0.5 mgd Plant	5 mgd Plant	50 mgd Plant	220 mgd Plant
Annualized Capital Cost	$0.32	$0.31	$0.22	$0.20
Annual O&M Cost	$0.12	$0.07	$0.06	$0.05
Total Annualized Cost	**$0.45**	**$0.38**	**$0.28**	**$0.25**

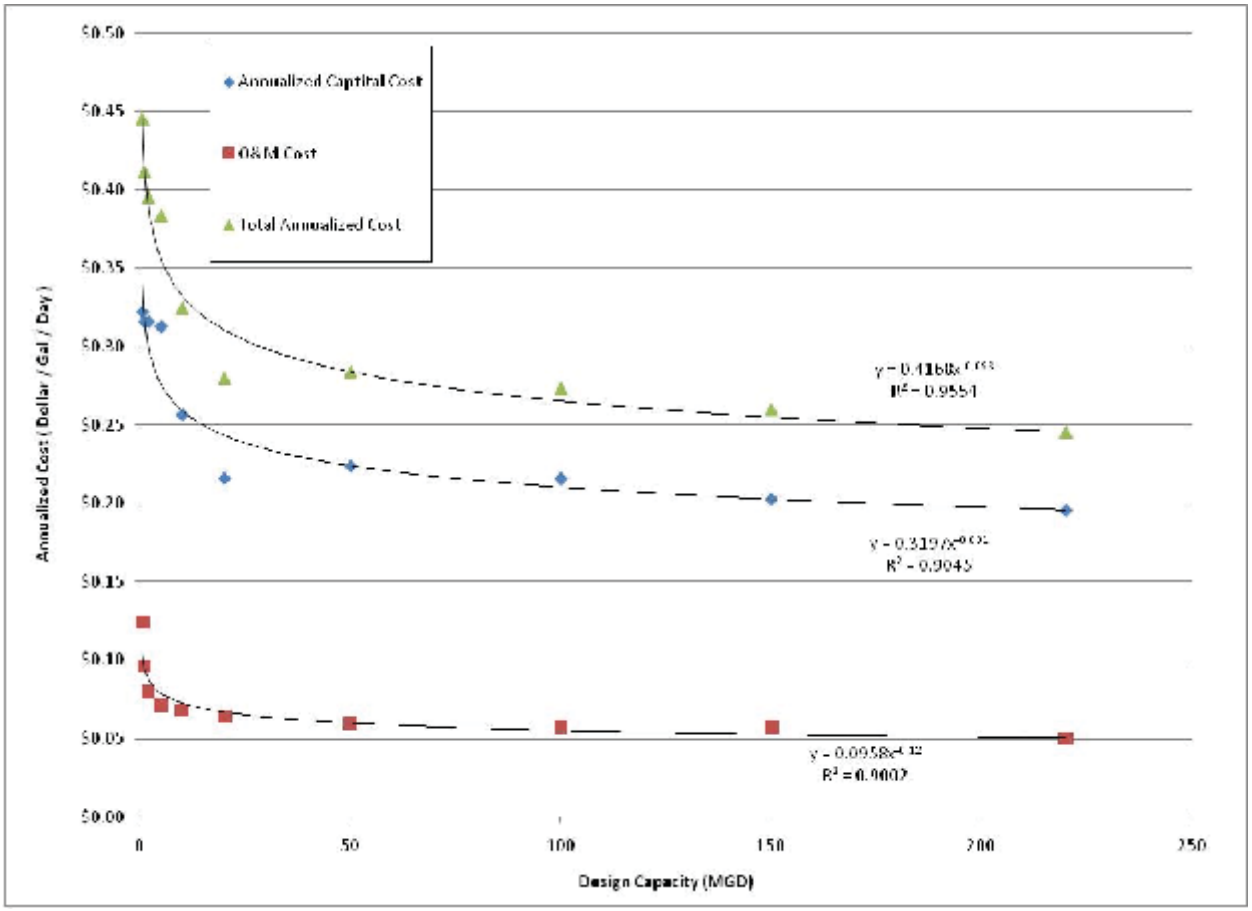

Figure 18-12. Annualized Capital and O&M Costs for Seasonal Reclaimed Water Upgrades for Membrane Plants

18.4.3 Extended Aeration Plants

Tables 18-36 through 18-39 show annualized capital and annual O&M cost estimates for upgrading both types of extended aeration plants (mechanical aeration and diffused aeration) to achieve Objective A nutrient removal and to provide Class A reclaimed water. The cost of the reclaimed water upgrade is also shown as a percent of the nitrogen removal upgrade cost.

TABLE 18-36.
ANNUALIZED CAPITAL COSTS FOR SEASONAL NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR EXTENDED AERATION PLANTS (MECHANICAL AERATION)

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Estimated Annualized Capital Costs for Nitrogen Removal Upgrade	$320,823	$1,674,036	$16,642,677
Estimated Annualized Capital Costs for Reclaimed Water Upgrade	$489,000	$3,477,834	$24,734,826
Total	**$809,823**	**$5,151,870**	**$41,377,503**
% Cost Increase for Reclaimed Water Upgrade	152%	208%	149%

TABLE 18-37.
ANNUAL O&M COSTS FOR SEASONAL NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR EXTENDED AERATION PLANTS (MECHANICAL AERATION)

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Estimated Annual O&M Costs for Nitrogen Removal Upgrade	$243,560	$433,659	$901,533
Estimated Annual O&M Costs for Reclaimed Water Upgrade	$438,600	$1,640,849	$6,138,590
Total	**$682,160**	**$2,074,508**	**$7,040,123**
% Cost Increase for Reclaimed Water Upgrade	180%	378%	681%

TABLE 18-38.
ANNUALIZED CAPITAL COSTS FOR SEASONAL NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR EXTENDED AERATION PLANTS (DIFFUSED AERATION)

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Estimated Annualized Capital Costs for Nitrogen Removal Upgrade	$46,889	$579,949	$2,904,885
Estimated Annualized Capital Costs for Reclaimed Water Upgrade	$489,000	$3,477,834	$24,734,826
Total	**$535,889**	**$4,057,783**	**$27,639,711**
% Cost Increase for Reclaimed Water Upgrade	1043%	600%	851%

TABLE 18-39.
ANNUAL O&M COSTS FOR SEASONAL NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR EXTENDED AERATION PLANTS (DIFFUSED AERATION)

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Estimated Annual O&M Costs for Nitrogen Removal Upgrade	$28,926	-$235,231	-$2,777,193
Estimated Annual O&M Costs for Reclaimed Water Upgrade	$438,600	$1,640,849	$6,138,590
Total	**$467,526**	**$1,405,618**	**$3,361,397**
% Cost Increase for Reclaimed Water Upgrade	1516%	-698%	-221%

18.4.4 Conventional Activated Sludge Plants

Tables 18-40 and 18-41 show annualized capital and annual O&M cost estimates for upgrading conventional activated sludge plants to achieve Objective A nutrient removal and to provide Class A reclaimed water. The cost of the reclaimed water upgrade is also shown as a percent of the nitrogen removal upgrade cost.

TABLE 18-40.
ANNUALIZED CAPITAL COSTS FOR SEASONAL NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR CONVENTIONAL ACTIVATED SLUDGE PLANTS

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Estimated Annualized Capital Costs for Nitrogen Removal Upgrade	$172,242	$864,178	$15,467,709
Estimated Annualized Capital Costs for Reclaimed Water Upgrade	$319,700	$2,592,643	$30,395,521
Total	**$491,942**	**$3,456,821**	**$45,863,230**
% Cost Increase for Reclaimed Water Upgrade	186%	300%	197%

TABLE 18-41.
ANNUAL O&M COSTS FOR SEASONAL NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR CONVENTIONAL ACTIVATED SLUDGE PLANTS

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Estimated Annual O&M Costs for Nitrogen Removal Upgrade	$177,887	$486,220	$3,598,252
Estimated Annual O&M Costs for Reclaimed Water Upgrade	$95,800	$726,717	$7,876,365
Total	**$273,687**	**$1,212,937**	**$11,474,617**
% Cost Increase for Reclaimed Water Upgrade	54%	149%	219%

18.4.5 Sequencing Batch Reactors

Tables 18-42 and 18-43 show annualized capital and annual O&M cost estimates for upgrading sequencing batch reactor plants to achieve Objective A nutrient removal and to provide Class A reclaimed water. The cost of the reclaimed water upgrade is also shown as a percent of the nitrogen removal upgrade cost.

TABLE 18-42.
ANNUALIZED CAPITAL COSTS FOR SEASONAL NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR SEQUENCING BATCH REACTOR PLANTS

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Estimated Annualized Capital Costs for Nitrogen Removal Upgrade	$0	$0	$0
Estimated Annualized Capital Costs for Reclaimed Water Upgrade	$270,914	$882,646	$3,477,834
Total	**$270,914**	**$882,646**	**$3,481,773**
% Cost Increase for Reclaimed Water Upgrade	undefined	undefined	undefined

TABLE 18-43.
ANNUAL O&M COSTS FOR SEASONAL NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR SEQUENCING BATCH REACTOR PLANTS

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Estimated Annual O&M Costs for Nitrogen Removal Upgrade	$1,576	($563)	$3,939
Estimated Annual O&M Costs for Reclaimed Water Upgrade	$294,835	$652,467	$1,640,849
Total	**$296,411**	**$651,904**	**$1,644,788**
% Cost Increase for Reclaimed Water Upgrade	18708%	-115891%	41656%

18.4.6 Trickling Filter, Trickling Filter/Solids Contact and Rotating Biological Contactor Plants

Tables 18-44 through 18-49 show annualized capital and annual O&M cost estimates for upgrading trickling filter, trickling filter/solids contact and rotating biological contactor plants to achieve Objective A nutrient removal and to provide Class A reclaimed water. The cost of the reclaimed water upgrade is also shown as a percent of the nitrogen removal upgrade cost.

TABLE 18-44.
ANNUALIZED CAPITAL COSTS FOR SEASONAL NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR TRICKLING FILTER PLANTS

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Estimated Annualized Capital Costs for Nitrogen Removal Upgrade	$344,062	$2,059,887	$24,020,776
Estimated Annualized Capital Costs for Reclaimed Water Upgrade	$319,700	$2,592,643	$30,395,521
Total	**$663,762**	**$4,652,530**	**$54,416,297**
% Cost Increase for Reclaimed Water Upgrade	93%	126%	127%

TABLE 18-45.
ANNUAL O&M COSTS FOR SEASONAL NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR TRICKLING FILTER PLANTS

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Estimated Annual O&M Costs for Nitrogen Removal Upgrade	$243,841	$707,439	$3,538,037
Estimated Annual O&M Costs for Reclaimed Water Upgrade	$95,800	$726,717	$7,876,365
Total	**$339,641**	**$1,434,156**	**$11,414,402**
% Cost Increase for Reclaimed Water Upgrade	39%	103%	223%

TABLE 18-46.
ANNUALIZED CAPITAL COSTS FOR SEASONAL NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR ROTATING BIOLOGICAL CONTACTOR PLANTS

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Estimated Annualized Capital Costs for Nitrogen Removal Upgrade	$345,625	$2,077,327	$24,474,041
Estimated Annualized Capital Costs for Reclaimed Water Upgrade	$319,700	$2,592,643	$30,395,521
Total	**$665,325**	**$4,669,970**	**$54,869,562**
% Cost Increase for Reclaimed Water Upgrade	92%	125%	124%

TABLE 18-47.
ANNUAL O&M COSTS FOR SEASONAL NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR ROTATING BIOLOGICAL CONTACTOR PLANTS

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Estimated Annual O&M Costs for Nitrogen Removal Upgrade	$304,861	$858,819	$4,545,367
Estimated Annual O&M Costs for Reclaimed Water Upgrade	$95,800	$726,717	$7,876,365
Total	**$400,661**	**$1,585,536**	**$12,421,732**
% Cost Increase for Reclaimed Water Upgrade	31%	85%	173%

TABLE 18-48.
ANNUALIZED CAPITAL COSTS FOR SEASONAL NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR TRICKLING FILTER/SOLIDS CONTACT PLANTS

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Estimated Annualized Capital Costs for Nitrogen Removal Upgrade	$216,251	$1,552,823	$19,453,578
Estimated Annualized Capital Costs for Reclaimed Water Upgrade	$319,700	$2,592,643	$30,395,521
Total	**$535,951**	**$4,145,466**	**$49,849,099**
% Cost Increase for Reclaimed Water Upgrade	148%	167%	156%

TABLE 18-49.
ANNUAL O&M COSTS FOR SEASONAL NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR TRICKLING FILTER/SOLIDS CONTACT PLANTS

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Estimated Annual O&M Costs for Nitrogen Removal Upgrade	$118,966	$443,788	$1,875,660
Estimated Annual O&M Costs for Reclaimed Water Upgrade	$95,800	$726,717	$7,876,365
Total	**$214,766**	**$1,170,505**	**$9,752,025**
% Cost Increase for Reclaimed Water Upgrade	81%	164%	420%

18.4.7 Membrane Biological Reactor Plants

Tables 18-50 and 18-51 show annualized capital and annual O&M cost estimates for upgrading MBR plants to achieve Objective A nutrient removal and to provide Class A reclaimed water. The cost of the reclaimed water upgrade is also shown as a percent of the nitrogen removal upgrade cost.

TABLE 18-50.
ANNUALIZED CAPITAL COSTS FOR SEASONAL NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR MEMBRANE BIOREACTOR PLANTS

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Estimated Annualized Capital Costs for Nitrogen Removal Upgrade	$0	$0	$0
Estimated Annualized Capital Costs for Reclaimed Water Upgrade	$319,700	$2,592,643	$21,025,321
Total	**$319,700**	**$2,592,643**	**$21,025,321**
% Cost Increase for Reclaimed Water Upgrade	undefined	undefined	undefined

TABLE 18-51.
ANNUAL O&M COSTS FOR SEASONAL NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR MEMBRANE BIOREACTOR PLANTS

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Estimated Annual O&M Costs for Nitrogen Removal Upgrade	$0	$0	$0
Estimated Annual O&M Costs for Reclaimed Water Upgrade	$95,800	$726,717	$5,512,715
Total	**$95,800**	**$726,717**	**$5,512,715**
% Cost Increase for Reclaimed Water Upgrade	undefined	undefined	undefined

18.4.8 High-Purity Oxygen Activated Sludge Plants

Tables 18-52 and 18-53 show annualized capital and annual O&M cost estimates for upgrading high-purity oxygen activated sludge plants to achieve Objective A nutrient removal and to provide Class A reclaimed water. The cost of the reclaimed water upgrade is also shown as a percent of the nitrogen removal upgrade cost.

TABLE 18-52.
ANNUALIZED CAPITAL COSTS FOR SEASONAL NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR HIGH-PURITY OXYGEN ACTIVATED SLUDGE PLANTS

	20-mgd Plant	220-mgd Plant
Estimated Annualized Capital Costs for Nitrogen Removal Upgrade	$1,646,890	$13,568,126
Estimated Annualized Capital Costs for Reclaimed Water Upgrade	$4,868,318	$43,053,142
Total	**$6,515,208**	**$56,621,268**
% Cost Increase for Reclaimed Water Upgrade	296%	317%

TABLE 18-53.
ANNUAL O&M COSTS FOR SEASONAL NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR HIGH-PURITY OXYGEN ACTIVATED SLUDGE PLANTS

	20-mgd Plant	220-mgd Plant
Estimated Annual O&M Costs for Nitrogen Removal Upgrade	$948,084	$6,905,503
Estimated Annual O&M Costs for Reclaimed Water Upgrade	$1,337,433	$11,033,098
Total	**$2,285,517**	**$17,938,601**
% Cost Increase for Reclaimed Water Upgrade	141%	160%

18.4.9 Lagoon Plants

Tables 18-54 through 18-57 show annualized capital and annual O&M cost estimates for upgrading both types of lagoon plants (aerated and facultative) to achieve Objective A nutrient removal and to provide Class A reclaimed water. The cost of the reclaimed water upgrade is also shown as a percent of the nitrogen removal upgrade cost.

TABLE 18-54.
ANNUALIZED CAPITAL COSTS FOR SEASONAL NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR FACULTATIVE LAGOON PLANTS

	0.5-mgd Plant	5-mgd Plant	50-mgd Plant
Estimated Annualized Capital Costs for Nitrogen Removal Upgrade	$783,969	$3,837,246	$24,741,394
Estimated Annualized Capital Costs for Reclaimed Water Upgrade	$270,914	$1,926,776	$13,703,494
Total	**$1,054,883**	**$5,764,022**	**$38,444,888**
% Cost Increase for Reclaimed Water Upgrade	35%	50%	55%

TABLE 18-55.
ANNUAL O&M COSTS FOR SEASONAL NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR FACULTATIVE LAGOON PLANTS

	0.5-mgd Plant	5-mgd Plant	50-mgd Plant
Estimated Annual O&M Costs for Nitrogen Removal Upgrade	$644,111	$2,119,896	$6,436,745
Estimated Annual O&M Costs for Reclaimed Water Upgrade	$294,835	$1,103,007	$4,126,468
Total	**$938,946**	**$3,222,903**	**$10,563,213**
% Cost Increase for Reclaimed Water Upgrade	46%	52%	64%

TABLE 18-56.
ANNUALIZED CAPITAL COSTS FOR SEASONAL NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR AERATED LAGOON PLANTS

	0.5-mgd Plant	5-mgd Plant	50-mgd Plant
Estimated Annualized Capital Costs for Nitrogen Removal Upgrade	$789,070	$3,870,397	$24,915,789
Estimated Annualized Capital Costs for Reclaimed Water Upgrade	$270,914	$1,926,776	$13,703,494
Total	**$1,059,984**	**$5,797,173**	**$38,619,283**
% Cost Increase for Reclaimed Water Upgrade	34%	50%	55%

TABLE 18-57.
ANNUAL O&M COSTS FOR SEASONAL NITROGEN REMOVAL AND RECLAIMED WATER UPGRADES FOR AERATED LAGOON PLANTS

	0.5-mgd Plant	5-mgd Plant	50-mgd Plant
Estimated Annual O&M Costs for Nitrogen Removal Upgrade	$490,941	$1,212,069	$4,519,475
Estimated Annual O&M Costs for Reclaimed Water Upgrade	$294,835	$1,103,007	$4,126,468
Total	**$785,776**	**$2,315,076**	**$8,645,943**
% Cost Increase for Reclaimed Water Upgrade	60%	91%	91%

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